Seat Interface Pressure Mapping to Improve Weight Shift Performance in Spinal Cord Injured Wheelchair Users

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Abstract

Objectives. This dissertation investigated the effects of using of a smartphone-based, on-demand seat interface pressure map on trunk activity, weight shifts, and self-efficacy in spinal cord injured wheelchair users in their home environments. We hypothesized that daily trunk activity and time spent in partial and full weight shift positions would increase with daily pressure map access and that self-efficacy for performing weight shifts would increase when education for pressure injury prevention included use of the pressure map and also when using the pressure map in one's daily routine.

Method. This longitudinal, within-subject, repeated measures study of 23 wheelchair users with complete spinal cord injury included an educational component grounded in social cognitive theory. Following education for pressure injury prevention and performance of weight shifts, each participant was provided with a mobile pressure mapping system to take home to use for week-long periods of time, alternated with periods without using the mapping system. Their trunk movement over a 4-week period was monitored with an accelerometer. Self-efficacy for performing weight shifts was evaluated with a 4-item scale before education, after education, after education using the pressure map for feedback and during each of the week-long periods of time at home.

Results. A statistically significant increase in trunk activity occurred with access to mobile, on-demand, seat interface pressure mapping in power and manual wheelchair users with spinal cord injury. The results suggested, but did not confirm with statistical significance, that there is a difference related to use of pressure map for time spent in

partial and full weight shift zones, however, 81% of the participants had a positive change in at least one movement-related variable while using the pressure map when compared with not using the pressure map. The results also suggest that self-efficacy for performing weight shifts is higher when pressure injury prevention includes pressure mapping as a guide when learning how to perform weight shifts. Finally, self-efficacy for movements that relieve pressure is significantly higher during periods of access to the pressure map than without.

Conclusions. We learned from this study that access to visual feedback from pressure mapping increases the types of movements that are protective against pressure injuries. Just as importantly, use of the pressure map improves self-efficacy for performing weight shifts in wheelchair users with spinal cord injury. Future research needs to explore who might benefit from this technology the most, when it should be introduced as an intervention strategy, and the effect of adding other features such as alerts, reminders, and the ability to self-track pressure-relieving behaviors over time.

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Seat Interface Pressure Mapping to Improve Weight Shift Performance in Spinal Cord Injured Wheelchair Users

Pressure injuries in individuals with spinal cord injuries (SCIs) remain one of the most dangerous secondary health problems encountered throughout their lifespan (National Spinal Cord Injury Statistical Center, 2017). At any given time, 35% of the 300,000 people with SCI in the United States will have a pressure injury related to sitting (National Spinal Cord Injury Statistical Center, 2017). An earlier study reported that 46% of the respondents with SCI self-reported having a pressure injury in the prior two years (Krause, 1998). With reported recurrence rates as high as 80% (Bates-Jensen, Guihan, Garber, Chin, & Burns, 2009; Niazi, Salzberg, Byrne, & Viehbeck, 1997) and 2^{nd} for cause of death when sepsis is present (National Spinal Cord Injury Statistical Center, 2017), there exists a critical clinical need to target prevention to avert severe complications and death. Despite the prevention efforts implemented over the years, pressure injuries continue to occur at an unchanging high rate of incidence in the SCI population, while incidence for other secondary conditions has reduced (National Spinal Cord Injury Statistical Center, 2018).

With the ongoing high incidence of pressure injuries in the SCI population, and the estimation that 80% of all pressure injuries are avoidable (Black et al., 2011), a critical challenge exists to develop and optimize effective prevention strategies in this population. Risk factors for developing a pressure injury are different for those with SCI than for the general population, requiring specific critical educational components. One key component is education to minimize prolonged pressure under the bony sacral, ischial, sacral and coccygeal areas (Consortium for Spinal Cord Medicine Clinical Practice Guidelines, 2014; Mayo Clinic, 2009; National Pressure Ulcer Advisory Panel, 2014) where they contact the sitting surface. General movement and trunk activity reduce prolonged pressure throughout the day, while weight shifts, made by the individual with SCI, are specific movements performed to change pressure distribution. Attention to performing these movements requires persistent attention to offload pressure between the buttocks and seat cushion of the wheelchair. Self-management of pressure redistribution, however, is adversely impacted by reduced or absent sensory function that cues the need to move or even to provide relief when done adequately.

Effective self-management strategies are needed to facilitate consistent daily engagement in use of weight shift maneuvers. Sustaining attention on weight shift movements, when there is a lack of sensation to provide a natural cue to move, is a challenge for wheelchair users with SCI. A new intervention strategy for this study uses visual feedback of pressure distribution on a mobile phone.

This study addresses pressure injury prevention broadly through the introduction of a novel approach using visual feedback about pressure distribution to improve weight shifting movements and self-efficacy in performing those movements. It is proposed that use of an on-demand, real-time, visual display of seat interface pressure (Vos-Draper, 2013; Vos-Draper, Rindflesch, & Morrow, 2013a)will provide critical visual feedback that allows wheelchair users with poor or absent sensation to immediately see the results of weight shifting and thus feel more capable in their ability to effectively manage pressure by using weight shifts. The purpose of this study is to explore the potential benefit of seat interface pressure mapping as a compensatory intervention strategy for increasing trunk movement, use of weight shifts, and self-efficacy in performing those movements in SCI wheelchair users.

Review of Literature

Pressure injuries: definition and risk factors. The National Pressure Ulcer Advisory Panel defines a pressure injury as "a localized injury to the skin or underlying tissue usually over a bony prominence, as a result of pressure, or pressure in combination with shear" (National Pressure Ulcer Advisory Panel, 2016, p.6). Factors that increase one's risk for pressure injury include physiological, biomechanical, and lifestyle factors. In all populations, there are general factors that can result in pressure injury, but there are specific challenges in the spinal cord injured population.

Physiological and biomechanical factors. Several physiological and biomechanical factors contribute to the manifestation of a pressure injury: pressure, shear, moisture, temperature, internal versus external forces, capillary flow and oxygenation at skin and tissue, and tissue tolerance (Defloor, 1999). Pressure is caused by perpendicular force contact with the individual's skin, and the effect on the skin and underlying tissues is based on time versus magnitude curve (Kosiak, 1961). Both high pressure for short durations and low pressure for long durations can result in tissue damage. Pressure is altered through seating equipment choices, positioning options, and by use of weight shift strategies aimed to reduce duration and magnitude of pressure when sitting.

Shear occurs with horizontal strain between skin or tissue and the support surface, such as when sitting or lying at an angle in relation to gravity. While the skin stays in place, the internal tissues shift and slide, causing breakdown of tissue internally (Goossens, 2004). Tissue tolerance to pressure depends on factors intrinsic to the individual such as nutritional status, hydration, the degree of atrophy, shape of underlying bony areas, and posture (Defloor, 1999).

It is well-established that individuals with SCI have a lower threshold for pressure when compared with neurologically normal individuals due to SCI-related changes in muscle tone, muscle bulk, bone shape (Linder-Ganz, Scheinowitz, Yizhar, Margulies, & Gefen, 2007; Linder-Ganz, Yarnitzky, Yizhar, Siev-Ner, & Gefen, 2009). Tissue tolerance for oxygen is impacted by physiological characteristics such as skin temperature, use of medications, tobacco abuse, other diseases such as diabetes (Defloor, 1999). Some of the factors affecting tissue tolerance threshold and oxygen are remediated through medical and lifestyle means. Each unmediated factor tips the scale unfavorably for an individual**.** An example of a remediating factor is movement to relieve pressure.

In this project, the primary biomechanical factor of interest is pressure. While shear and tissue tolerance for pressure and oxygen are recognized as equally important, measurement is more complex, and the intent for this work is to identify a modifiable risk factor with established means of measurement in the field. While measurement methods exist for shear and tissue tolerance for pressure and oxygen, they are less amenable to use outside of a research environment and especially more difficult to measure over long periods of time without disrupting an individual's daily routine or putting the skin at risk due to size of the measurement instruments (Akins, Karg, & Brienza, 2011; Goossens, 2001).

Lifestyle factors. Lifestyle factors include all those impacted by each individual’s unique environment and resources that interact with their ability to manage skin health (Clark et al., 2006). Each individual's routines, rituals, and contexts contribute to either protecting or making one at more risk for pressure injuries. In a continuation of Clark et al.’s work, Jackson et al. (2010) narrowed the wide range of lifestyle risk factors down to eight that relate to pressure injury risk. These factors include perpetual danger, change or disruption of routine, the decay of prevention behaviors, lifestyle risk-ratio, individualization, the simultaneous presence of prevention awareness and motivation, lifestyle trade-off, and access to needed care, services and supports (Jackson et al., 2010). Factors that most impact seated pressure need additional explanation to clarify why adherence to weight shifting routines is critical, yet challenging to do.

Perpetual danger means that the risk for developing an ulcer is always present. Unanticipated problems occur. An air-filled seat cushion may suddenly lose air, resulting in high pressure at bony areas. Permanent lack of sensation on the buttocks means that the protective feedback loop alerting one to move or check the seat cushion is absent. Wheelchair users must maintain constant attention on the need to remove pressure across areas at risk. Distractions may deter focus from completing weight shift maneuvers. Perpetual danger also implies that one must always be aware of their risk and be on alert.

Change in routine impacts typical behavior because of the contextual or environmental differences that result. A delayed flight could result in a wheelchair user forced to sit in their chair for several additional hours unexpectedly. When starting a new job, a wheelchair user may forget to perform weight shifts due to demands of learning new work tasks. Disruptions cause distractions that shift focus away from protective behaviors.

The decay of prevention behaviors results in a decline in using prevention strategies over time. Despite how well an individual understands the need to change position frequently, as other demands arise for an individual, the attention on weight shifting behavior deteriorates over time. Individuals with SCI lack the normal sensory feedback that stimulates the need to move when pressure accumulates. Prevention behaviors that aren't paid attention to through conscious awareness and effort are difficult to maintain, especially when sensation is absent.

Prevention of pressure injuries. Prevention requires focusing on several factors simultaneously. Initially, when an acute spinal cord injury occurs, prevention is managed by hospital caregivers who carefully monitor the skin and adherence to turning schedules. During initial rehabilitation after a spinal cord injury, the individual receives structured instruction for nutrition, skin checks, changing position, equipment to reduce risks such as specialized seat cushions, wheelchairs, or mattresses, and methods for completing weight shift maneuvers and timing of those. Once the individual is discharged from the hospital or rehabilitation center, they are required to self-manage this challenging task while also learning how to navigate their routines with new limitations. Education at this point typically is delivered through outpatient therapies where behaviors to shift weight are encouraged and reinforced. After completion of outpatient therapy, the individual may see their spinal cord injury team annually for follow up, and they may meet with a seating specialist to assess pressure distribution via seat interface pressure mapping. In between visits, however, the individual is expected to self-manage their skin health. Unfortunately, education efforts, while they continue to be increasingly supported by scientific evidence, have not been effective in reducing the incidence of pressure ulcers in this population.

Education. Several clinical guidelines exist regarding recommendations for pressure relief strategies. There are slight differences among them in recommendations for frequency and duration of weight shift maneuvers and rigorous evidence supporting the recommendations is limited. Before mid-1990's, recommendations informed individuals with SCI complete a full pushup every 10-15 minutes and hold for at least 5 seconds. Now, the consensus is that weight shifts should occur by leaning forward or over side of the chair if able and tilt or recline if using a power wheelchair every 15-30 minutes and last for 1-2 minutes each time (Consortium for Spinal Cord Medicine Clinical Practice Guidelines, 2014; Mayo Clinic, 2009; National Pressure Ulcer Advisory Panel, 2014). Weight shifts are movements that redistribute weight. If physically able, forward leans and side to side leans are preferred to shift the weight away from the ischial tuberosities and coccyx regions. For those unable to lean and resume upright safely, use of a power wheelchair with tilt (and sometimes recline) allows the user to tilt up to 50 degrees or recline up to 180 degrees which effectively shifts the weight posteriorly.

Individuals with acute SCI receive education from their care team about how to self-manage their skin health. Weight shifts and validation of success is completed with visual inspection of the skin each day. Weight shifts and skin checks are two behavioral strategies that individuals with SCI are taught to self-manage to prevent pressure injuries after they leave the hospital with a new SCI. Adherence to these guidelines is challenging, however, and it seems more difficult as time passes from initial injury (Thietje et al., 2011). At 30 months after dismissal from inpatient rehabilitation, less than 50% of participants with SCI were able to recall necessary pressure injury prevention knowledge.

Moreover, even when knowledge was retained, and the physical ability to perform adequate weight shifts existed, the behaviors for preventing pressure injuries were not consistently carried out. The less-engaged participants completed fewer weight shifts. The participants with greater self-involvement in their pressure injury prevention efforts, independent of the level of function, had fewer pressure injuries than those who relied on caregivers to manage their skin (Anderson & Andberg, 1979). This study provides some evidence that effective self-management is an essential factor in the prevention of ulcers. Interventions, then, should focus on improving self-management abilities.

Specific technologies aimed at pressure injury prevention in wheelchair users. For almost 50 years, clinicians and researchers have been interested in devices to monitor pressure, weight shifts, send alerts, provide cues, or track movement patterns in wheelchair users. We are now in an era of technological advancement that allows large amounts of data to be collected and analyzed almost instantly and then displayed on a smartphone, which up to 85% of wheelchair users with SCI carry (National Spinal Cord Injury Statistical Center, 2017). This advancement in technology provides new opportunities to revisit the use of effective feedback to encourage weight shifts.

Learning from previous work in this area will inform future work around developing more effective self-management strategies for pressure injury prevention, specifically with a focus on increasing weight shifts and maintaining the behavior of moving over time to reduce the risk for developing pressure injuries. Merbitz, King, Bleiberg, and Grip (1985) monitored push-up adherence for seven newly injured wheelchair users using a pressure sensor and data logger to count offloads of >3 seconds throughout a full day. They found that pushup performance varied widely among participants; some would sit for long periods between pushups but then do several in a row, others had reduced frequency at certain times of the day, creating inconsistency in performance. They found that none of the participants were able to complete pushups consistently at least every 20 minutes all day long as recommended (Merbitz, King, Bleiberg, & Grip, 1985). While this study was performed to monitor response to a training device, the baseline phase findings are interesting because they show typical movement patterns using objective measures and early attempts to quantify movement patterns in wheelchair users.

Patterson and Fisher (1980) characterized pressure relief movement patterns across a full day for community-based individuals with SCI. They enrolled 12 individuals with paraplegia. The participants sat on a foam cushion, monitored with small pressures sensors for weight shifts. The average time between pushups of >5 seconds duration was determined to be 29.6 minutes (SD=27.5). Shorter duration movements (>1 second) were more common, occurring an average of 10.1 minutes (SD=6.4) (Patterson & Fisher, 1980). They did not look at durations above five seconds separately, so it is unknown how long participants maintained the typical weight shift. Interestingly, over a period of 6 months, none of the 12 individuals developed a pressure injury. It is feasible that aside from the individuals likely having other protective factors, they may also have benefitted from the more frequent movements of shorter duration because it appears movement was occurring at a rate close to movement in non-SCI individuals, but only for movements of 1 second or less in duration.

Another group of investigators, interested in how individuals in wheelchairs move during a specific functional task (computer use), recruited fourteen individuals with SCI in an acute rehabilitation facility. The participants were monitored with a pressure sensing pad on their seat cushion during the computer-based functional activity. The investigators observed the number of pressure relief maneuvers per hour and the duration of the maneuvers. Less than 50% of the participants performed pressure relief maneuvers every 15 minutes, which was the recommended dosage of movement at the time of the study. Less than 30% held the movement for >20 seconds (Stinson, Schofield, et al., 2013). One limitation of this study is that the individuals were asked to focus on a computer-based task for one hour while they were monitored. This new task may have distracted them from performing their typical weight shifting behaviors. It is not evident in the article if the subjects were instructed to complete weight shifts as they typically would or not. Nonetheless, these results also support the theory that individuals with SCI who use wheelchairs move much less than healthy individuals do when they sit, and this contributes to increased risk for pressure injury when combined with the other risk factors.

There are several examples in the literature of early attempts to improve weight shifting behavior to prevent pressure injuries in wheelchair users using technology to provide feedback to the user. Some of the devices provided cues or prompts to perform a weight shift based on time. Others provided a printout of weight shift patterns for review at a later time. One of the most significant limitations in the success in the subsequent adoption of previous technologies on a broad scale was in processing capabilities of the mapping technologies and computers in use at the time. Another major limitation is that the technologies were targeted toward training in the use of weight shifts, or monitoring adherence to recommended schedules, but not in use of technology as a permanent compensatory strategy. Just as we might wear glasses to compensate for impaired vision, a compensatory device is required to assist an individual with impaired sensation to "see" how effective they are in managing pressure distribution. This different way of approaching the use of technology to impact weight shift performance has the potential to improve an individual's self-efficacy for completion of weight shifts in a positive way.

As described in Table 1, in the studies that evaluated the use of feedback methods to impact completion of weight shifts, performance was improved while the feedback was used. However, when the feedback was removed, the frequency declined to near baseline levels. These examples provide support that feedback, when used as a compensatory strategy for absent sensory stimuli are effective in improving performance of weight shifts but did not result in long term behavior change. The technologies used in early studies addressing weight shifting behaviors were designed as temporary training devices to teach wheelchair users how to perform pushups or leans correctly. One exception is the use of a timer to remind one to shift weight. This technology is simple and relatively easy to adopt, however, the user is still missing important feedback about how well they redistributed pressure when they moved. Despite the technology and design limitations at the time of development, the results show that technology used in the past to provide feedback has shown some benefit in improving weight shift performance.

Table 1
Technologies developed to facilitate pressure injury prevention over the past 50 years

Author(year)	Device	Purpose	Criteria or Features	Information from Device
(Fordyce & Simons, 1968)	Push-up training device with alarm	Train users to avoid loud signal by completing pushups before time runs out and to holding pushup for the duration.	Adjustable 10 or 20 min frequency and 5-10 second duration; alarm sounds at the end of the period. Push-up stops alarm. Alarm sounds if not held for the full length.	Goal: wean from the device. Counts # of pushups with/without alarm, # held for the duration or not.
(Roemer, Lee, & Meisel, 1976)	Warning device with reminders as a training aid	Designed for use by those with tetraplegia and monitors leans instead of pushups	LED on armrest flashes R or L as prompt for leans; adjustable volume alarm if no lean after initial prompt. Adjustable frequency 2-30 minutes and duration 10-60 seconds. LED stays on until completed.	Goal: wean from the device. Doesn't provide feedback on behavior over time, but provides an immediate visual prompt and auditory alarm consequence if weight shift not completed.
(Temes & Harder, 1977)	Device for training those with new SCI	Patient training in adherence to schedules	Pressure sensing pad and timer. Adjustable to 15, 30, or 60-minute frequencies and between 5-60 second durations. If no pushup by the designated time, then adjustable volume alarm.	Goal: wean from the device and retain behaviors. Provided # weight shifts AND # of alarms for the day.
(Patterson & Fisher, 1980)	Monitor pressure relief patterns	Patient monitor for adherence	Pressure sensors under ischial tuberosities with 7-hour recording time capability.	Two pressure sensors count all offloads of >1 sec as a pushup
(Werner & Perkash, 1982)	Detection of loss of air in an air-filled seat cushion	Alert device for cushion failure	Pressure sensing pad between the cushion and wheelchair sling. If pressure increased to 50mmHg, an alarm was triggered.	An early attempt to solve the problem of deflating air cushions.
(Fisher & Patterson, 1983)	Monitor pressure relief patterns in w/c users	Caregiver monitoring of patient adherence	Pressure sensors under ischial tuberosities. Measured time between pushups >1 second and >5 seconds.	Push up occurrence determined by a 10mmHg drop in average pressure

Author(year)	Device	Purpose	Criteria or Features	Information from Device
(Cumming, Tompkins, Jones, & Margolis, 1986)	The Wheelchair Patient Monitor	The device uses alarms and stores recorded performance	Pressure sensing pad and microprocessor checks weight shifts every second and monitors the duration of detected changes. Settings are adjustable for individualization of programming.	If meeting criteria for duration/frequency, then weight shift is counted.
(Grip & Merbitz, 1986)	Timer Logger Communicator	Training device for completion of push-ups	Pressure sensors detect reduced overall pressure and define as pushup if of >5 sec durations; Prompts provided based on time, and are LED or audio. Alarms also optional as LED or audio.	Printed logs provided to wheelchair user for review of trends and past behavior. Feedback not provided immediately.
(Bain & Ferguson-Pell, 2002)	Device to monitor remote sitting behaviors	Identify patterns of sitting behavior in w/c users. Intended for research.	Mini pressure logger. Device "woke up" every 5 seconds to record pressure and processed sensor readings to look for changes over time of at least 10%. If the total value is close to zero across the mat, then indicates full pushup and counts as one pushup. Center of pressure to determine the symmetry of sitting	No feedback provided to the user. Technology bulky, cumbersome and requiring frequent clinician/researcher interaction.
(Wilson et al., 2004)	Mobile Activity Monitor	Track weight shifts with visual feedback to the wheelchair user	Wireless with four force sensors and blackberry pager. The ratio of pressure between sensors used to determine weight shifts side to side and front/back.	Visual feedback provided about pressure and completion of weight shifts with trend data for a full day at a time. Flower design with petals with lengths corresponding to the frequency of weight shifts throughout the day shown.
(Brizzi et al., 2008)	Automated pressure relief timer provides cues to perform pressure relief maneuvers	Training device with the goal of reducing the need for healthcare worker providing reminders	Prompts every 15 minutes to perform 15-second pressure relief. Auditory and visual feedback can be self-selected by the user.	Auditory and visual prompts for the need to relieve pressure.
(Yang, Chang, Hsu, & Chang, 2009)	Data logger for detecting sitting behaviors remotely	Describe sitting behavior through long-term monitoring in wheelchair users	Data logger with six pressure sensors (four in the back, one under each thigh). Ratios used to determine weight shifts side to side and front/back. When the sum of pressure reached zero, indicates out of the chair.	Data processing limitations exist. Data sampled 1/10Hz. No feedback to the user.

Author(year)	Device	Purpose	Criteria or Features	Information from Device
(Eneling et al., 2009)	Bluetooth enabled pressure monitor	Monitor seated pressure, provide alerts	64 pressure sensors; alarm signals user when "dose" of pressure has reached designated critical level (not defined); feedback to the user about weight shift adherence. Use of an initial clinical fitting to create an individualized baseline.	The live pressure sensor information is not provided visually to give immediate feedback. Alarm used to remind to weight shift.
(Verbunt & Bartneck, 2010)	Sensing mat with multiple biofeedback modes	Determine if tactile or audio feedback is more useful as reminders.	Use of a commercial mat, microcomputer and chest belt with vibration. Chest belt vibrates on the side of body person needs to move toward for optimized posture, based on sensor readings from the pressure mat.	Tactile via chest strap. No visual feedback.
(Chenu et al., 2013)	Pressure mat with smartphone visual display and audio/tactile feedback to the user using a watch	A device intended for home use by individuals at risk for pressure ulcers to self-monitor live pressure and to receive input in the form of prompts and alarms when needed.	Wireless technology utilized. Smartphone used. Live pressure feedback to the user.	Author developing alerts, alarms. Indicated plan for testing the device with more subjects in 2013, no studies found to date as follow up.

Smartphones are becoming ubiquitous (Pew Research Center, 2015) and are equipped to facilitate behavior-shaping strategies to impact weight shifts. Combined with the rich visual information provided by seat interface pressure mapping (IPM), this type of feedback could be a compelling behavior change driver because it can provide real-time, immediate information about the need to shift weight or about the effectiveness of a weight shift.

A novel approach using mobile pressure map. Seat IPM is a tool used in specialty seating clinics to evaluate individuals for most appropriate cushion choices.

IPM is also used to educate individuals on how to get themselves positioned optimally for reduced pressure to high-risk areas and can be used to educate caregivers as well. IPM consists of a flexible, thin mat with 256-1028 pressure sensors. The mat rests between an individual's bottom and their seat cushion. A display shows pressure readings in a gradient of colors that represent the values. This vibrant visual display is a simple way to visualize high-risk areas. The pressure mapping system used in this study included a pressure sensing mat (Boditrac) by Vista Medical (Vista Medical, Winnipeg, CA). The mat consists of conductive spandex fabric layers and 4-way stretch water resistant cover. The mat stretches and drapes over various types of cushions and is resistant to accidental spills. These characteristics were identified as priorities by a focus group at Mayo Clinic that was comprised of wheelchair users with SCI (Vos-Draper, Rindflesch, & Morrow, 2013b). The pressure mat connects to a small mini-computer (3" x 4" x 1" dimension). A small battery powers the system. The device connects by a wireless internet connection to a smartphone, which then displays the pressure distribution on an app on the phone.

The visual feedback of pressure distribution is the primary feature of interest as a potential intervention in this study. A RCT clinical trial study (N=422) in an intensive care unit (ICU) on nursing behavior in turning patients used pressure mapping as an intervention strategy at the patient's bedside. Those in the control group used a regular ICU bed. The intervention group used a specialized bed that included an integrated interface pressure map with a display at the bedside visible to the nursing staff (Behrendt, Ghaznavi, Mahan, Craft, & Siddiqui, 2014). The nurses who had access to the live pressure mapping display while turning their patients reported significantly higher levels of feeling confident in their ability to effectively offload the at-risk areas. The patients in the treatment group also had significantly fewer pressure injuries (.9%) compared to the control group (4.8%, P=.02), indicating the strong potential of live visual pressure mapping feedback in preventing pressure injury related to movement. The results are the first to study the effect of interface pressure mapping on reduction in pressure injury incidence and also the first to report the use of pressure mapping as a visual feedback tool to increase confidence in performing weight shifts. This study provides substantial evidence that visual feedback can impact self-efficacy based on the nurse's anecdotal comments reported in the article about improved confidence in their performance as well as showing that increased movement or more effective movements reduced the pressure injury risk for the patients who used the pressure mapping beds.

Health behavior change: focus on movement. There are four characteristics of weight shifts to consider as outcome measures: frequency, consistency, quality, and duration. Frequency refers to how often weight shifts occur in a single time period, while consistency refers to how stable the frequency is over a series of time periods. For example, an individual with a high frequency of weight shifts may have performed 50 weight shifts in a given day, but perhaps 45 of them were completed in the morning and the remaining five in the evening. Conversely, if consistent, the user may have completed five weight shifts per hour, every hour they spent in the chair on a given day. Quality refers to how effective the weight shift is in redistributing pressure. The weight shifts need to be of sufficient magnitude to result in adequate redistribution, and this distance will be unique to each due to body habitus, equipment, and injury level. Each of these characteristics is equally important to monitor.

Weight shifts correlate with reduced pressure injury risk. The debate is ongoing on the optimal dosing of movement. In a systematic review, investigators attempted to tease out specific protective factors for pressure injury prevention (Coleman et al., 2013). They determined that 36/54 studies met their review criteria mentioned movement as an outcome measure positively correlated with pressure injury prevention. Of these studies, 29/36 concluded a significant association exists between increasing movement overall and a reduced risk for developing a pressure injury. While identifying specific movements, how much, and for how long was not possible due to the different protocols in the studies, the results are clear that increased movement has a protective impact on reducing the risk for pressure injuries. Evidence about the quality and quantity of movement required for skin protection exists, but with some discrepancies.

Two studies present conflicting results regarding movement as a protective factor. Krause and Broderick (2004) surveyed 633 community-based individuals with SCI and history of at least one pressure injury to identify protective factors against recurrence of pressure injury. They could not determine a statistically significant correlation between completion of weight shift maneuvers and reduced risk of recurrence (Krause & Broderick, 2004). Also reported in a survey study by Raghaven, Raza, Ahmed, and Chamberlain (2003), of 472 community-based individuals with SCI, no correlation was found between self-reported frequency of weight shifts and reduced pressure injury prevalence(Raghavan, Raza, Ahmed, & Chamberlain, 2003). A crucial distinction is that both surveys relied on subjects' self-report of completion of weight shifts. Self-report has significant limitations as an outcome measure in general due to recall bias but is a trade-off to the convenience offered in obtaining information from large samples.

There are two important conclusions from recent studies on what type of movements are most effective in redistributing pressure. These are: 1) the percent change in pressure is directly proportional to magnitude of movement, and 2) even small movements can result in a significant reduction in pressure at highest risk bony areas (Burns, 1999; Hobson & Tooms, 1992; Sonenblum & Sprigle, 2011a, 2016b; Sonenblum, Vonk, Janssen, & Sprigle, 2014; Sprigle, Maurer, & Soneblum, 2010; Stinson, Gillan, & Porter-Armstrong, 2013). While these conclusions don't provide prescriptive magnitudes of movement and do not provide a direct correlation between the percentage of change and reduction in pressure injury incidence with movement, they do demonstrate that movement is a viable outcome of interest to target with an intervention.

Mobile technologies for health behavior change. Mobile phones present an opportunity to place behavior change tools in individual's hands on a device they are likely already using. Many apps deemed as useful for behavior change incorporate principles of a theoretical model. (Cowan et al., 2013) reported that few apps used any theoretical constructs. Those that did include theoretical constructs utilized the Health Belief Model 32% of the time with focus on self-efficacy.

Social cognitive theory: self-efficacy. To test the effectiveness of a new intervention, grounding it within a specific health behavior change theory provides a necessary framework within which to implement and assess the intervention (Lyons, Lewis, Mayrsohn, & Rowland, 2014). The social cognitive theory (SCT) focuses on how individuals learn and apply new behaviors (Bandura, 1997). Self-efficacy is a crucial concept of social cognitive theory, and it will be assessed concerning the performance of weight shifts in this study (Glanz, Rimer, & Viswanath, 2008) while using visual feedback to guide weight shifts.

The social cognitive theory (SCT) emphasizes the importance of self-efficacy in affecting how humans learn and maintain new behaviors. In SCT, behavior change and maintenance of behaviors result from an individual's expectation about how well they can perform an activity in addition to the strength of their belief that the activity will result in the desired outcome. These factors are called self-efficacy expectations and outcome expectations respectively. One can have positive self-efficacy expectations with low outcome expectations, and this can adversely affect the performance of a behavior. If both types of expectations are positive, one may be more likely to be motivated to engage in a specific behavior (Bandura, 1997). The belief that tilting a wheelchair to 50 degrees results in enough pressure relief under the ischial tuberosities is an example of a self-efficacy expectation. If that person, however, does not believe that tilting the chair results in reduced risk for pressure injury development, they are not likely to engage in the behavior and this is an example of an outcome expectation. Therefore, in planning a pressure injury prevention strategy and outcome measure, both types of expectations must be considered.

In the SCT, there is reciprocal determinism between the person, their environment, and their behavior (Bandura, 1977). This means that learning occurs through social observation as well as through the following methods: verbal persuasion and mastery experience. When using the pressure map image to determine how pressure distribution changes as they move, the individual receives direct feedback to either validate or negate their belief about how movement affects pressure distribution. The pressure mapping feedback provides information to help the individual master their weight shift maneuvers while receiving input from a clinician to validate that pressure redistribution was optimized. Mastery occurs through performance of tasks that are challenging, resulting in increased self-efficacy (Bandura, 1977).

Self-efficacy for a specific prevention method can be measured using a survey to determine where on a continuum an individual’s beliefs about their ability to perform a task lie. We can also learn about outcome expectations through questions such as: How sure are you that performing weight shifts has a positive impact on pressure distribution? (Bandura, 2006).

While movement as an outcome is an objective measure that we can measure with an accelerometer, we know from the qualitative work on lifestyle factors related to pressure injury risk in wheelchair users with SCI that multiple additional factors impact an individual's performance for completing weight shifts. Given the individualized nature of these factors, understanding an individual's sense of self-efficacy toward weight shifts may provide one way to measure the internal processes leading someone to shift weight.

A goal to increase movement in the form of weight shifts requires individual behavior change. A wheelchair user needs to make a diligent effort throughout the day when they are sitting to move well enough to redistribute pressure adequately. Behavior change to weight shift more often, more consistently, for the right distance and duration can be compared in complexity to nutritional goals for maintaining a healthy weight which also requires diligent and ongoing conscious effort. In the dietary field, interventions grounded in behavior change theory have been most successful in helping individuals succeed in making needed changes (Azar et al., 2013; Pagoto, Schneider, Jojic, DeBiasse, & Mann, 2013). Wheelchair users face many of the same environmental, personal, and social challenges that impact their decision to make needed weight shifts as all of us who try to maintain a healthy diet on an ongoing basis. Grounding a lifestyle-based health behavior change intervention in a theoretical framework provides structure for designing an intervention method, implementing it, and then assessing the success of the intervention. The combination of a theory-based approach toward self-management with emerging use of mobile technologies presents substantial potential for development of effective pressure injury prevention strategies.

Significance

For individuals living with SCI, the risk for developing a severe pressure injury is always present. Without sensation to guide changes in position to alleviate pressure, these individuals move significantly less than individuals with neurologically normal sensory systems. The literature lacks definitive evidence for prescriptive frequency, magnitudes, and durations of movement but there is evidence that moving is protective in wheelchair users. Action to relieve pressure can be defined as overall trunk movement which includes trunk motions one does during typical daily activities, such as subtle leaning while reaching for objects. Specific trunk motions called weight shifts can also define movement. Weight shifts require the individual to move a specified distance to improve pressure distribution on their wheelchair seat cushion. One of the primary challenges in determining prescriptive amounts of weight shifts is the heterogeneity of the SCI population and the multiple factors that contribute to pressure injury risk. Despite this, there is clear evidence that specific weight shift movements in the form of forward leans, side leans, and use of tilt on a power wheelchair to at least 30 degrees results in significant reductions in pressure at the seating surface.

Additionally, trunk activity, in general, could be a prevention strategy that has been overlooked and requires further investigation. As recent studies have indicated, even a little movement can be beneficial, and these smaller movements are completed more often than the typically prescribed weight shifts throughout a wheelchair user's typical daily routine. Thus, an intervention targeted toward increasing both types of movement focuses on a universal protective factor that all wheelchair users with SCI need to employ, no matter their injury level or type of chair they use.

Self-efficacy for completing weight shifts in the wheelchair can be measured by asking specific questions related to how confident an individual is about their ability to performing the recommended movements. Individuals with higher self-efficacy and self-management of health-related behaviors tend to experience more success in making changes to improve and maintain their health. For this reason, an intervention that targets increasing an action such as trunk activity and weight shifts should also focus on improving self-efficacy for that task.

This study will examine two interventions to increase movement and self-efficacy related to pressure injury prevention in wheelchair users with SCI. First, consistent education for performing weight shifts will be provided to all participants, grounded in the principles of social cognitive theory, regarding pressure injury risk and use of weight shifts. Additionally, the participants will use a mobile seat interface pressure mapping system that gives them live, real-time, visual feedback on the distribution of pressure between them and their seat cushion. This type of feedback works as a compensatory strategy for lack of sensation and will be used following education training, as it provides virtual modeling of the desired outcome (reduced pressure) and is an integral part of the education module.

The findings of this study will inform clinicians and investigators whether the use of mobile seat interface pressure mapping as a compensatory-based intervention has a positive impact on trunk movement and self-efficacy for completing weight shifts in wheelchair users who lack sensation.

Specific Aims

Primary aim. Trunk movement (trunk activity and weight shifts) in seated wheelchair users with SCI will increase when the user has access to a mobile seat interface pressure mapping system to self-monitor pressure distribution on their wheelchair seat cushion.

Hypothesis 1. Overall trunk activity will be higher during periods of mobile pressure map use. The percentage of time classified as active each day will be higher during mapping phases.

Hypothesis 2. Weight shifts will increase with access to mobile pressure mapping. The proportion of in-chair time spent in weight shift positions each day will be higher during pressure mapping phases.

Secondary aim. Self-efficacy for the use of weight shifts as a pressure ulcer prevention strategy in wheelchair users with SCI will increase through structured education and with access to the mobile seat interface pressure mapping system to self-monitor pressure distribution on their wheelchair seat cushion.

Hypothesis 3. Self-efficacy for weight shift scores will be higher after using pressure map feedback during the initial research session compared to baseline score and post-education-only score.

Hypothesis 4. Self-efficacy for weight shift scores will be higher during periods of access to pressure mapping feedback than periods without the use of the pressure map.

Method

Research Design

This study design was longitudinal, within-subject, with repeated (A-B-A-B) measurement of the outcomes of interest. Interventions included education for pressure injury prevention with a focus on technique for completing pressure-relieving weight shifts and use of seat interface pressure mapping as visual feedback of seated pressure distribution.

Study Participants

Data collection occurred between October 2016 and August 2017 at Mayo Clinic, Rochester, MN. Wheelchair users (n=23) with an existing complete spinal cord injury participated in this study. Recruitment of participants followed Mayo Clinic and University of Minnesota's Institutional Review Boards (IRB) and HIPPA guidelines. The primary source of recruitment was from the Spinal Cord Injury Outpatient Program and Seating Clinic at Mayo Clinic. Study flyers were placed in approved common areas and on the Mayo Classifieds to attract potential participants. Participants were contacted by phone, email, and/or mail per IRB approved transcripts to inquire about interest in participating in the study. Participants received remuneration of $100 for participating in this study. They were not reimbursed for travel or parking expenses.

Inclusion criteria. Inclusion criteria included the following: community-dwelling, aged 18-80, male or female, spinal cord injury (SCI) with complete sensory loss on buttocks and legs, and full-time wheelchair use for mobility. Participants were required to be independent using a smartphone. As far as mobility, they needed to tolerate sitting for a minimum of six hours per day, seven days per week and can perform weight shifts independently whether by leaning or through use of power seat functions on their wheelchair.

Exclusion criteria**.** Individuals were not eligible for this study if they had an existing pressure injury on their skin at any part of their sitting surface (buttocks and posterior thighs). Individuals who lived in a long-term care facility or group home, requiring 24 hours/day assistance were excluded. Participants were screened by phone or in person using the Six-item Screen for Cognitive Impairment (Callahan, Unverzagt, Hui, Perkins, & Hendrie, 2002) determined whether the participants were allowed to participate in this study. None of the participants considered for enrollment failed the Six-item Screen for Cognitive Impairment. Thus, all participants had the ability to learn new information and to be able to recall the information over the study period.

The target number of participants was 30 based on 80% power and a significance level of .05 for medium effect size (f=0.27). The original estimation included a 20% attrition rate, which would result in 26 participants. Recruitment reached 25 before study enrollment was stopped. The primary reason enrollment was stopped was due to an unanticipated problem with the web application support. An update in security practices required costly modification ($150K) to the web application to meet Mayo Clinic information technology criteria. The team allowed a time-limited exception to allow ongoing use of the web application after determining that the risk for security breaches were small for this project, until August 2017, at which time the web application was disabled. Recruitment from selected sources by restricting enrollment to individuals without skin issues. Many of the individuals seen in the seating clinic identified as potential participants had pressure injuries as the reason they were being treated. The slow recruitment combined with time-limitation on use of the web application required stopping recruitment before a total of 30 participants were enrolled.

Interventions

Two interventions were provided to all participants who participated in this study: education for completion of weight shift maneuvers to redistribute pressure on their buttocks and use of seat interface pressure mapping as a visual feedback while performing weight shifts.

Education. Structured education for performing weight shift maneuvers and general pressure injury prevention for individuals with SCI was provided to all participants. Education materials included two online videos: written patient education materials from Mayo Clinic, and verbal instruction and feedback by researcher who has experience providing occupational therapy services in the seating clinic. The videos used were created and distributed by the Spinal Cord Injury Research Center at MedStar National Rehabilitation Hospital (Spinal Cord Injury Research Center at MedStar National Rehabilitation Hospital, 2013). The first video was eight minutes long and focused on skin breakdown and pressure injury prevention in persons with SCI. If the participant was a manual wheelchair user, they watched two additional videos from the same organization to learn about weight shift techniques. One of the videos focused on techniques for performing side leans, and the other focused on the performance of forward leans. For participants who used a power wheelchair, a separate video was shown with a focus on weight shifts using power tilt. Individuals with SCI performed all demonstrations in the videos. The primary goal of this education was to provide consistent knowledge to all participants about how to perform weight shifts to relieve pressure on the buttocks while sitting in a wheelchair to reduce the risk of pressure injuries.

Written education materials for pressure injury prevention and how to perform weight shifts were provided and reviewed verbally with each participant (Mayo Foundation for Medical Education and Research, 2012a, 2012b). Pictures of the stages of a pressure injury to facilitate skin checks were included in the education folder as a reference for the participant to use during skin checks. The focus on skin checks was necessary because participants were asked to closely monitor their skin throughout the study and document any problems. The pressure injury stages pictures provided a reference to compare their skin against and language for documenting any changes they observed.

The education methods used in this study aligned with the principles of the social cognitive theory to facilitate learning (Bandura, 1977). The purpose in providing the education was to ensure all of the participants received uniform instruction in how to perform pressure-relieving weight shifts and to facilitate understanding of the importance of completing them as a protective measure against pressure injury development. Because each participant entered the study with varying levels of understanding about pressure injury risk and knowledge of how to complete weight shift maneuvers, the education component was critical to ensure all participants received the same information in the same way to create a new baseline. For example, participants who received inpatient rehabilitation following their acute SCI 20 years ago were likely instructed in the use of push-ups from their armrests to relieve pressure and this differs from current education for using leans instead due to changes in recommended protocols (Coggrave & Rose, 2003). In social cognitive theory, one assumption is that optimal learning occurs through observing others who are similar to them perform the task or behavior. Therefore, the education provided in this study used short videos showing individuals with SCI demonstrating the strategies for shifting weight to redistribute pressure.

Another component of the education included demonstration and practice completing weight shift maneuvers specifically for pressure redistribution. Each participant performed specific types, sequences, and repetition of weight shifts using the criteria in Table 2. Following each step of the education process, teach-back methods were employed to ensure the participant understood the information. An example of a teach-back moment is: “Please demonstrate a full forward lean similar to the one you observed in the education video we just viewed.” During teach-back, verbal reinforcement was provided for correct responses, aligning with the principles of teaching under social cognitive theory.

The specific weight shift movements included in this study were determined from the results of two studies on the effectiveness of weight shifts on pressure redistribution. In a study on the effectiveness of power tilt at specific positions for pressure redistribution (Sonenblum & Sprigle, 2011b) tilt correlated with a significant reduction in pressure as measured by a seat interface pressure sensor and oxygen perfusion at the skin specifically when power tilt was fully employed. For partial posterior tilts, the results were less dramatic but demonstrate at least a small positive change in skin perfusion at 30 degrees tilt. Thus, in this study, a full weight shift was defined as tilting as far back as the chair's power seat actuators allowed, typically 50-55 degrees, and for a partial tilt, 30 degrees of power tilt was selected.

For manual wheelchair users, the weight shift movements selected for use in this study are a slightly modified version of those used by Sonenblum et al. (2014) in assessing weight shifts and pressure distribution on various seat cushions. In their study, all weight shifts correlated with a reduction in seat interface pressure and a concurrent increase in buttock blood flow, proportional to the magnitude of shift except for what they defined as small forward leans. (Sonenblum et al., 2014).

The weight shift sequences for manual wheelchair users, and the power chair users who preferred to lean instead of use tilt in their daily routines for managing pressure, includes a series of six leans described in Table 2.

Table 2

Criteria for Completing the Weight Shift Sequence During the Initial Research Visit

		Criteria for Weight Shifts
Manual Wheelchair Users	Upright	Show the position you typically sit in when in your chair.
	Full forward lean	Lean all the way forward as far as you can, ideally with your trunk/abdomen resting on your legs.
	Partial forward lean	Lean forward to rest your elbows on your legs.
	Full side leans	Lean all the way over to the side, reaching your hand toward the floor, going as far as you are able without needing help to return to upright. You can support yourself by resting your hand on the tire on the floor or hooking the opposite arm/hand around the armrest, tire, or back cane to keep your balance. Try to lift your opposite hip slightly off the seat cushion when you lean to the side.
	Partial side leans	Lean to the side, resting your elbow on the armrest if you have one. Try to go about half the distance you moved for a full lean.
Power Wheelchair Users	Tilt to 30 degrees (Partial tilt)	Tilt your seat back about halfway.
	Tilt all the way back(Full tilt)	Tilt your seat all the way back, as far as it will go.
	Upright	Bring your tilt into the most forward or upright position you can without losing your trunk balance.

Seat interface pressure mapping. While performing this weight shift sequence, participants were able to visualize their seated pressure distribution on the computer screen via BodiTrac mat and FSA version 4.1 software (Vista Medical, Winnipeg, CA). Use of seat interface pressure mapping (IPM) to guide weight shifts provided immediate visual feedback about how the distribution of pressure between themselves and their wheelchair seat cushion changed during weight shifts (Figure 1).

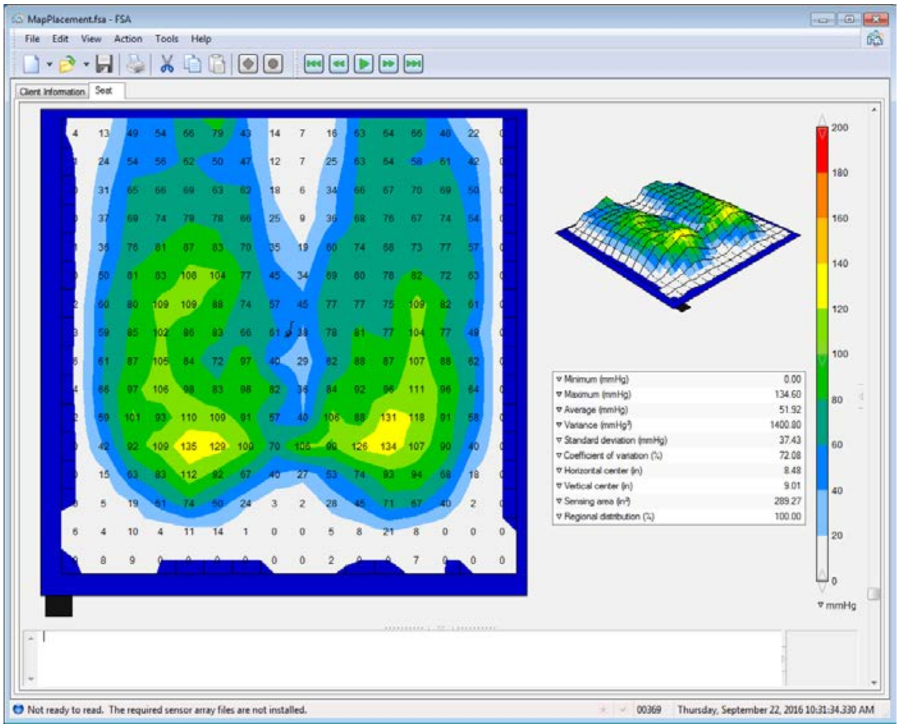

Figure 1. FSA software screenshot of a participant in sitting position.

There were two different seat interface pressure mapping systems used in this study. The first, BodiTrac with FSA software, was designed for clinical use. The FSA software was used on a computer to show the participant their pressure during the weight shift sequence. Use of the clinical pressure mapping system allowed recording and exporting of pressure map data for use in analysis. The second pressure mapping system was a prototype mobile smartphone web application and pressure map intended for use by wheelchair users at risk for pressure injuries to use at home, all day, as on-demand, real-time visual feedback regarding pressure distribution. The mobile system showed the live pressure distribution on a smartphone screen. Both pressure mapping systems used the BodiTrac pressure mat.

Initial visit pressure mapping. For the initial visit, the BodiTrac pressure mat and FSA 4.1 software was used to record pressure distribution during the weight shift sequence described earlier. Recordings were made at a 5Hz sampling rate. This recording was saved and used for determining thresholds for classifying field-based movements at the end of the study. Examples of what the participant observed while performing their weight shifts are shown in Figure 2. The pressure for the participant shown in Figure 2 was distributed under the ischial tuberosities and surrounding tissues. When tilted all the way back the pressure shifted to the sacral region and lower back. The pressure mapping system was also used during the weight shift sequence as a visual feedback tool for each participant to use as a guide while completing their weight shifts. The BodiTrac's mat resolution was 16x16, providing 256 points of pressure measurement.

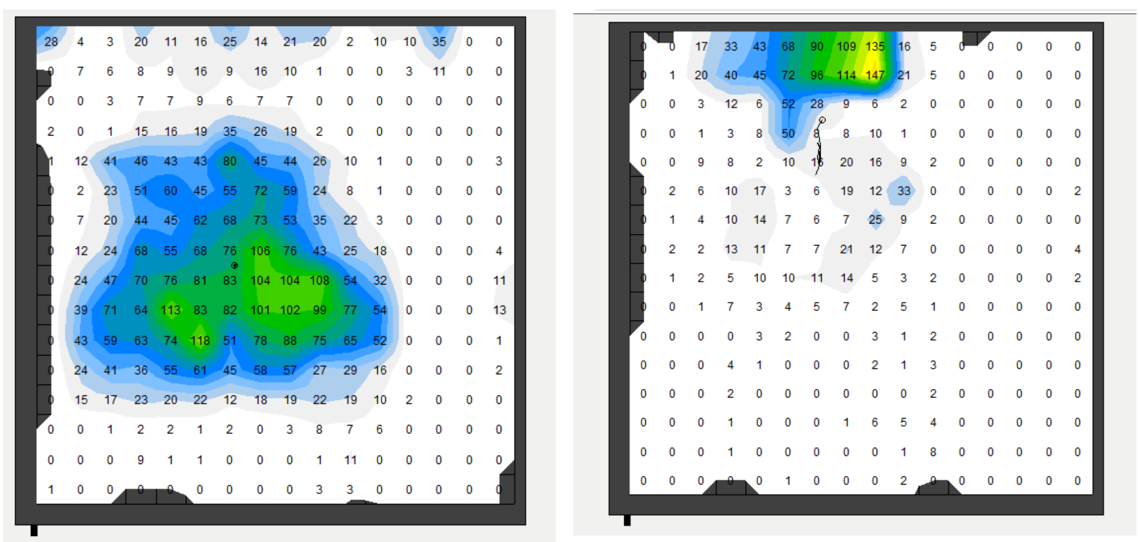

Figure 2. Pressure map recordings are showing upright position in a power wheelchair user (left) and fully tilted position in the same user (right). Pressure is redistributed to the sacral region. Pressure is shown in mmHg.

Field-based pressure mapping. For the field-based portion of the study, the mobile pressure mapping web application was used. Each participant was provided with an Apple iPhone 5, a rechargeable battery, a small mini-computer (Raspberry Pi), and a web-based application on the iPhone for visualizing the live pressure map (Figure 3). The mobile system was developed to work with the BodiTrac mat because it was the only commercially available pressure mat that had 4-way stretch for optimal fit on contoured surfaces.

Figure 3. Pressure mat on wheelchair seat cushion (left); Mini-computer and battery (right). (iPhone not shown.)

The prototype mobile version of the pressure mapping system was developed at Mayo Clinic and is not commercially available (Vos-Draper, 2013; Vos-Draper et al., 2013a). The mini-computer connected to the iPhone through the Personal Hotspot feature of the phone. The mini-computer software pulled live data from the BodiTrac mat to view it on the phone. Users were able to view a real-time, dynamic pressure map image similar to the one they see on clinical software (Figure 4).

The web application was in prototype form during this study and capabilities were limited to live viewing of the map and capability to save 15-second recordings to review later if desired. Mayo Clinic's information technology department at the Center for

Innovation provided maintenance for the web application and server during the study. Access to user-level interaction with the web application was not available to the researcher.

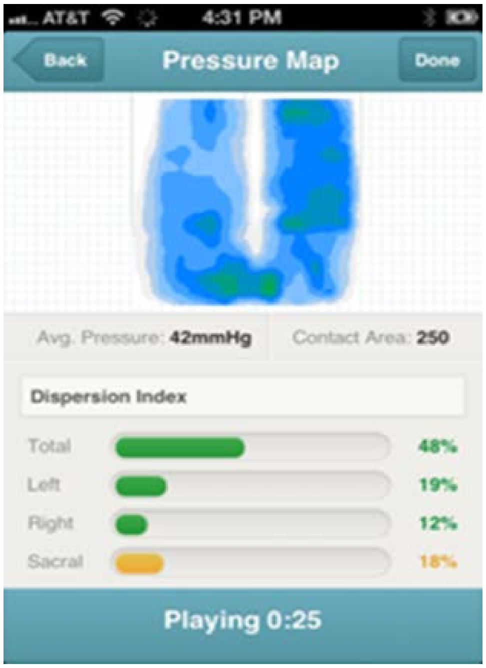

Figure 4. Screenshot of mobile pressure mapping web application shown on a smartphone screen.

In alignment with social cognitive theory, the use of models, whether interpersonally provided by a peer like them or through media sources using simulation is necessary. The pressure map's visual display provided a symbolic model of pressure distribution on the sitting surface in the form of colors that shift as the person moves. The pressure map image, because it provides a simulation of the pressure and the effect movement has on the distribution of pressure, provided a viable method for teaching and reinforcing the use of weight shifts to redistribute seated pressure. Red colors indicate highest pressures and blue colors indicate lowest pressures.

The visual feedback from the mobile pressure mapping system was the primary intervention during the field-based, or in-home, a portion of this study. While not a new concept for the participants who had all had previous pressure mapping assessments with an occupational or physical therapist at least once since the onset of their SCI, the use of mobile pressure mapping outside of the clinic for all-day use by wheelchair users was a novel use of the technology.

Outcome Measures

The primary outcome was movement of the wheelchair user's trunk while sitting in their wheelchair, in their natural environment, and going about their normal routine. The dependent variables in this study include trunk movement (both trunk activity and weight shifts) and self-efficacy for performing weight shifts. Trunk activity and weight shifts were measured with an accelerometer placed at the sternum. The second outcome was the wheelchair user's rating of self-efficacy for performing weight shifts to redistribute pressure. Self-efficacy was measured through a four-question survey developed for this study.

Accelerometer to measure trunk movements. Trunk movement was measured with a single tri-axial accelerometer place at the participant's sternum with a chest strap. The accelerometer used in this study was either the Actigraph^{TM} GT3X+ or the GT3X+BT (Actigraph, Pensacola, FL). The accelerometer measured linear accelerations along each of the three axes within a dynamic range of ± six or eight units of gravity depending on the Actigraph^{TM} model used. The devices are small (~4.6cm x 3.3cm x 1.5cm), lightweight (19 grams) and have battery life sufficient for use over a four week period with a requirement for charging of the device one time during the study (Figure 5). Estimated battery life for both is 22 days at 30Hz sample rate if the option for idle sleep mode is disabled. The wGT3X+ can store up to 90 days of raw data, and the wGT3X+BT can store up to 298 days when collected at 30Hz. The data is transformed from analog to digital via 12-bit conversion and stored onto flash memory in raw, non-filtered format.

Figure 5. Actigraph™ wGT3X+ shown with y-axis in a superior position.

A 1" wide black elastic strap was used to hold the device snugly around the chest of each participant (Figure 6). Straps were adjustable and fastened via a clip buckle. For participants who were not able to unclip/clip the buckle, the strap was pulled on/off over the head and shoulders while it remained fastened and then adjusted around the chest or they were assisted by their personal care attendant to manage donning the device each day. While the device is water-resistant, participants were discouraged from wearing it while bathing or swimming to keep the strap dry for minimal skin irritation.

Figure 6. Actigraph™ and chest strap.

Before the initial research visit, a high-speed USB connection to a computer was used to initialize the accelerometers. Initialization settings in ActiLife software 9.0.0 included the following parameters: sample rate of 30Hz, no filter applied, all three axes enabled, and idle sleep mode disabled to ensure 24 hours/day data collection. Start time was set to begin before the participant's research visit. No end time was specified except for three of the first participants. In those cases, an end time was specified for precisely 28 days from the start. However, this did not accommodate unanticipated delays in data collection due to equipment challenges and was changed for subsequent participants to avoid additional loss of data. The LED indicator option was disabled because the device was often worn on outside of clothing and participants preferred to not call attention to it via blinking light.

The sample rate of 30Hz was adequate to capture the desired trunk movements. Ambulation frequency bands are described as between .3 to 5 Hz (Godfrey, Conway, Meagher, & O'Laighin, 2008), and trunk movement in a seated position is expected to be well within that range and closer to 0.5Hz (Fenety, Putnam, & Walker, 2000; Marenzi, Bertolotti, & Danese, 2014). Data was stored on the device until it was uploaded to a computer for analysis.

During data import into the computer, Actilife 9.0.0 options for the low-frequency extension, step count, and inclination count were not selected. The resulting .gt3x formatted raw data was exported to a .csv file using the raw to raw batch export feature in Actilife. The .csv file did not include timestamps to reduce file size but did include initialization time and date and download time and date in the 10-row header. Below the header, each row contained the raw acceleration samples for each of the three axes. It was discovered that the order of the three axes was not consistent with the labels in the user manual, so this was corrected during analysis. Also, the two Actigraph™ models had opposite orientations in the y- and x-axes, which were corrected in the analysis. Table 3 describes the orientation of the accelerometer in different positions in relation to gravity and the resulting value in the axis that is aligned with gravity.

Table 3.
Accelerometer Orientation and Acceleration Values in Static Positions for the Wgt3x+Accelerometers.

Trunk Position (90-90-90 degree angles)	x-axis	y-axis	z-axis
Upright	0	-1	0
Right	1	0	0
Left	-1	0	0
Tilted back	0	0	-1
Forward	0	0	1
Upside down	0	1	0

Figure 7 shows the orientation of the axes when the accelerometer as worn by participants in this study if they are sitting perfectly upright at 90 degrees, trunk perpendicular to the floor.

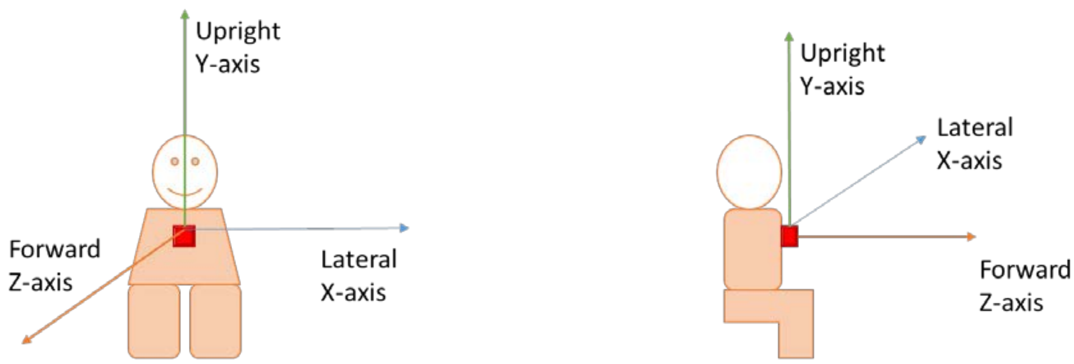

Figure 7. The position of the accelerometer on participants and corresponding direction of each axis.

Self-efficacy scale for performing weight shifts. The second outcome of interest is self-efficacy around the performance of weight shifts, which was measured with a series of four questions about self-efficacy for weight shifts for pressure injury prevention. The items were written specifically for this study following principles outlined in Albert Bandura's guide to developing self-efficacy assessments (Bandura, 2006). The four questions are shown in Table 4. The initial question targeted an individual's outcome belief that completing weight shifts prevents pressure injuries. Three subsequent questions assessed judgment of their immediate capability to complete weight shift maneuvers based on three criteria: effectiveness (moving far enough to impact pressure distribution), consistency (completing weight shifts every half hour), and duration (holding weight shifts for two minutes).

Table 4.
Self-Efficacy for Weight Shifts to Prevent Pressure Injuries.

I believe I am able to:	Not at all sure								Completely sure	
1. Prevent pressure injuries by performing weight shifts at regular intervals when I am in my wheelchair.	1	2	3	4	5	6	7	8	9	10
2. Move far enough during weight shifts to relieve pressure at my high-risk areas.	1	2	3	4	5	6	7	8	9	10
3. Consistently perform weight shifts at least every half hour during the day.	1	2	3	4	5	6	7	8	9	10
4. Hold my weight shifts for two full minutes as recommended for at least half of my weight shifts.	1	2	3	4	5	6	7	8	9	10

While other instruments to measure self-efficacy are available and psychometrically tested, none specifically address one's beliefs around their ability to self-manage pressure distribution when sitting in their wheelchairs. While not tested for validity, the four questions used in this study were carefully constructed following Bandura's guide, using clinical guideline driven criteria for questions three and four. The risk of using a more general, but well-tested self-efficacy instrument is reduced specificity to the variable of interest and failure to detect change. In this case, one's beliefs around completing weight shifts are specific. Test-retest reliability was assessed by administering the test twice within two days and without a change in intervention between administrations.

The self-efficacy questions were administered up to eight times per participant, at specific points of time in the study. Table 5 shows this sequence. The total score for each of the administrations is the average of the four responses multiplied by 10. The total score range is 1-100. A score of 100 indicates the strongest belief in capability and a one indicates the lowest.

Table 5.
Repeated Measures of Self-efficacy for Weight Shifts Timeline

SE1	Baseline (Prior to education or use of the pressure map.)
SE2	Post-education
SE3	Post-education + Use of pressure map to guide weight shifts
SE4	Two days after initial research visit
SE5	During the first week of mobile pressure map use
SE6	While not using pressure mapping system
SE7	During the second week of mobile pressure map use
SE8	While not using pressure mapping system

Procedures

Participation in this research study required an initial research visit to Mayo Clinic at the start of the study, followed by four weeks of field-based data collection and, when possible, ended with a return visit to Mayo Clinic for the return of equipment. When the participant was not able to return, arrangements were made with the participant for the return of the study materials. Details regarding the events that occur at each part of the study follow (Table 6)

Table 6.
The Flow of Study Activities.

Pre-Visit	Six-item Screen for Cognitive Impairment Initiate consenting process Schedule research visit Prepare equipment: calibrate mat, charge phone and battery, Initialize accelerometer
Research Visit	Consent process Examine skin, determine eligibility to continue Collect demographic information Set up pressure mat on chair's cushion (do not start pressure mapping software) Self-efficacy questions (SE1) Education for completing weight shifts (video, demonstration, discussion, and education materials); practice completing weight shifts. Self-efficacy questions (SE2) The participant performs the weight shift sequence while observing live pressure map on the computer; record weight shifts on pressure map software Self-efficacy questions (SE3) Review study responsibilities, instructions for using equipment
Field Collections	Self-efficacy questions (SE4) on day 1 or 2 in field Participant follows the schedule for alternating time periods with use of pressure mapping system and without pressure mapping system At the end of each period, self-efficacy questions repeated (SE5-8)
End of Study	Return equipment (mobile pressure mapping system and accelerometer) Qualitative comments collected Return of daily log

Pre-visit. The BodiTrac pressure mats were calibrated according to manufacturer instructions for automatic calibration using the calibration jig and pneumatic air pump. The phones, rechargeable batteries, and accelerometers were fully charged and initialized. Data plans for the phones were purchased and activated.

When possible, study information related to the consenting process was provided to the participants to review before the initial visit. A 2-hour appointment was scheduled for each participant to report to Mayo Clinic's seating clinic for the initial visit.

Initial research visit. At this visit, the investigator obtained consent in writing from the participants. The first self-efficacy assessment (SE1) was completed after obtaining demographic information. The self-efficacy questions were provided on paper to the participant and each was encouraged to read the questions and circle the numbers corresponding to their responses unless they preferred to verbally state the response for the researcher to record. The same method was used for all three self-efficacy assessments completed on the first visit.

Next, the participant transferred out of their chair to the mat table (using ceiling lift with assistance when necessary). The participant's skin on buttocks was checked to confirm that skin was intact. The BodiTrac pressure mat was placed on top of the participant’s seat cushion on their wheelchair. After verification of skin health, the participant transferred back to their wheelchair with the pressure mat placed between them and the seat cushion.

The participant was shown how to place the pressure mat on their chair and allowed to practice smoothing it under themselves as needed. The accelerometer was put on the participant using the chest strap. The participant was shown how to position the accelerometer over the sternum and they were asked to where it in same position each day, positioning it as high as they could tolerate (strap under arms, accelerometer over the sternum). They were instructed to wear the chest strap and accelerometer each day over the four-week study period. Additionally, teach-back questions were used after each step.

Education, as described above, was provided to each participant using the videos and written education materials. Teach-back methods were used to ensure the participant understood the information.

Skin check methods, including the use of a mirror as needed to see the skin, were reviewed with each participant. Because of the potential risk for skin breakdown during the study, with the addition of material between them and their seat cushion, participants were asked to document the status of their skin each day on a daily log that was provided to them (Appendix A). Additionally, the participants were also instructed to document the time they spent in their chairs each day in their daily log by indicating an in-chair time and an out-of-chair time.

Self-efficacy assessment (SE2) was completed after video and written education for performing weight shifts was provided and before the use of the pressure map. The participants did not have access to their previous responses as they answered each successive set of questions.

The participants each completed a weight shift sequence (WSS) of specific leaning or tilting movements (Table 7), repeating the entire sequence three times. Seat interface pressure mapping software and the accelerometer recorded movement and pressure distribution during the WSS to use for activity classification of trunk activity and weight shifts. The seat interface pressure mapping system was active on the computer screen, in view of the participant, while the participant completed the WSS. If needed, the researcher moved the laptop computer so the participant could observe the display to ensure the participant could see feedback about their performance.

Table 7.
Weight Shift Sequence (WSS): Each Completed Three Times.

Leans	full forward lean→upright→full right lean→upright→full left lean→upright→partial forward lean→upright→partial right lean→upright→partial left lean
Power Tilt	full tilt→upright→30 degree tilt

Finally, the participants were provided with an iPhone with the mobile pressure mapping web application active. Instructions were provided for connecting the map wirelessly through the personal hotspot and for opening and interacting with the application. A data plan for the mobile phone was provided with one month of service.

Participants were allowed time to practice weight shifts again using the mobile pressure mapping system to guide their movements, and they were given as much time as needed to observe their pressure distribution on the iPhone while practicing weight shifts. The self-efficacy assessment (SE3) was repeated after the participant had indicated they felt comfortable using the mobile pressure mapping system.

Final instructions at the end of the initial visit included the timing of use of the mobile pressure mapping system at home. They were instructed to use the system for one week, remove it for one week, then repeat. Participants were instructed to use the system as much or as little as they want during the "on" days as indicated on their calendars. Reminders were given to the participants to strive for completion of weight shifts as instructed every 30 minutes and to hold them for a full two minutes when sitting in the wheelchair.

Data collection in the field. The participant was contacted on day 2 to repeat the self-efficacy assessment (SE4). The answers to the questions were recorded for the participant. Contact was most often through Email or text messaging. The questions were provided in writing, and the participants responded with their scores. Most participants preferred this approach to a phone call.

Each week, the investigator contacted the participants for the administration of the self-efficacy questions, for a total of four additional times (SE5, SE6, SE7, and Se8). At each contact, the participants were also reminded of their schedule for map use and asked about their skin health. At week two, they were reminded to charge the accelerometer.

If skin changes were identified by the participant, based on National Pressure Injury Advisory Panel criteria (National Pressure Ulcer Advisory Panel, 2014) and reported to the investigator by the participant during weekly phone calls during the study, the investigator assisted the participant in determining appropriate medical avenue for caring for the injury.

Final visit. Participants returned for a final visit at the end of the study period. There were exceptions to this. For example, one participant needed to be admitted to the hospital (for non-skin related medical care). In cases when it was not possible to return in person, the equipment was either picked up by the researcher or mailed in pre-postage paid packaging sent to the participant. During the final visit, the participants provided comments about their experience using the pressure mapping system. The comments were written in the participant's daily logs. In some cases, the participant provided the comments verbally and were immediately written in the participant logs. While not a formal qualitative process, the feedback and comments were reviewed during analysis to provide context to each user's results.

Data Handling

All study data were de-identified for analysis. Names and birthdates were removed. Accelerometer data was imported, and raw data was saved in .csv format. Data from daily logs and self-efficacy assessments were stored digitally on password-protected (Mayo Clinic and University of Minnesota) computers, transferred from Mayo Clinic to University of Minnesota through encrypted USB drive after identifying information was removed. The data was maintained following HIPAA and patient privacy regulations.

Demographic data. Demographic data included age, sex, years of onset since SCI, level of SCI (cervical, thoracic, or lumbar), type of wheelchair used, type of seat cushion used, and history of pressure injury or surgery to repair an ulcer in the past.

Each participant's study days were allocated to one of the four phases of the study, which alternated between using and not using the pressure map. The schedule provided to the participant was considered first for allocating the days to each phase, then the participant's daily log notes, which at times indicated special circumstances when the schedule was not followed. The phases were assigned as follows: Phase A1=first mapping period, Phase B1=first non-mapping period, Phase A2=second mapping period, and Phase B2=second non-mapping period.

Attempt to avoid bias in assigning study days to each phase occurred by using two strategies. Phase allocation was completed before review and analysis of the accelerometer data so that judgment would not be affected by the perception of increased or decreased activity on a given day. Then, a second investigator, blinded to the first investigator's responses, reviewed the calendars and daily logs to classify each study day. When there was disagreement about how days were allocated, the two researchers reconciled the dates together until there was agreement.

Accelerometer data. Post-processing of the raw accelerometer data, to prepare it for statistical analysis, was completed with custom software in MATLAB (Mathworks, Natick, MA). The raw accelerometer data for each participant included about 77,760,000 rows of data. Figure 8 provides an example of one participant's full accelerometer data across the study days.

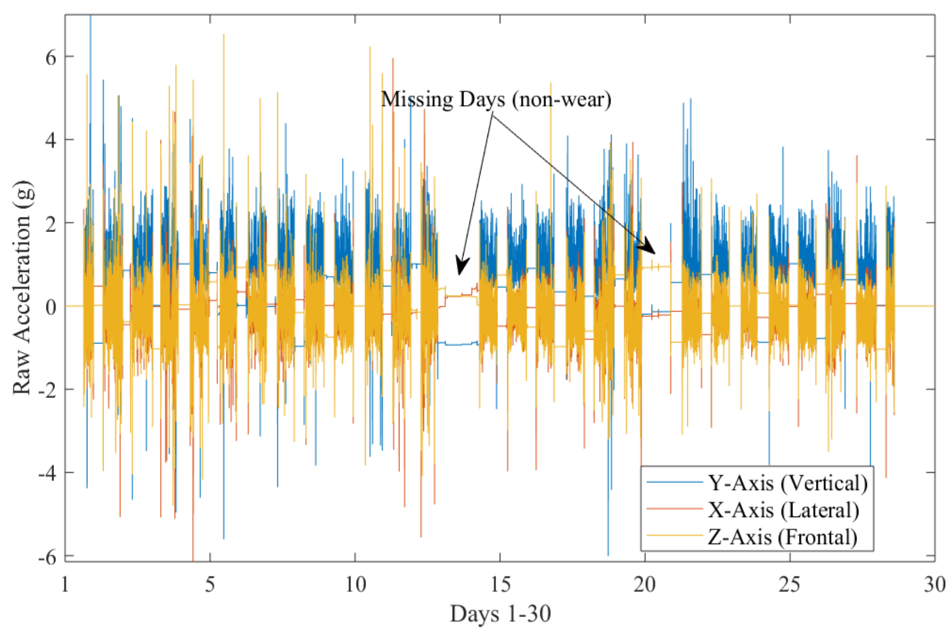

Figure 8. Raw accelerometer data (~77,760,000 samples) across entire field-based collection period for visualization of the entire study period. In this example, two missing days are apparent at day 14 and 21. By visualizing data as a whole, general patterns in wear time were observed for each participant before further analysis.

Identify weight shift sequence and time in accelerometer data. The weight shift sequence (WSS) provided a period of monitored and structured activity with a secondary validation source (pressure map recording). It was essential to identify this small segment of data from the larger file to use for training and testing code to use for classifying the remaining data. The start time for the WSS was calculated in seconds from the time of initialization of the accelerometer. For example, if accelerometer initialization occurred at 3:15:00 PM and the weight shift sequence started at 4:15:00 PM, exactly one hour, or 3600 seconds, had elapsed. The pressure map recordings were used as verification of start time by comparing the timestamps on the pressure map recordings and elapsed time for accelerometer data. Knowing the start time in seconds for the WSS allowed the ability to index into the raw data using seconds and sampling rate to determine the exact rows of data needed for analysis of specific days without the use of timestamps for each sample. An example of a segment of raw accelerometer data that includes the 10-minute WSS segment is shown in Figure 9.

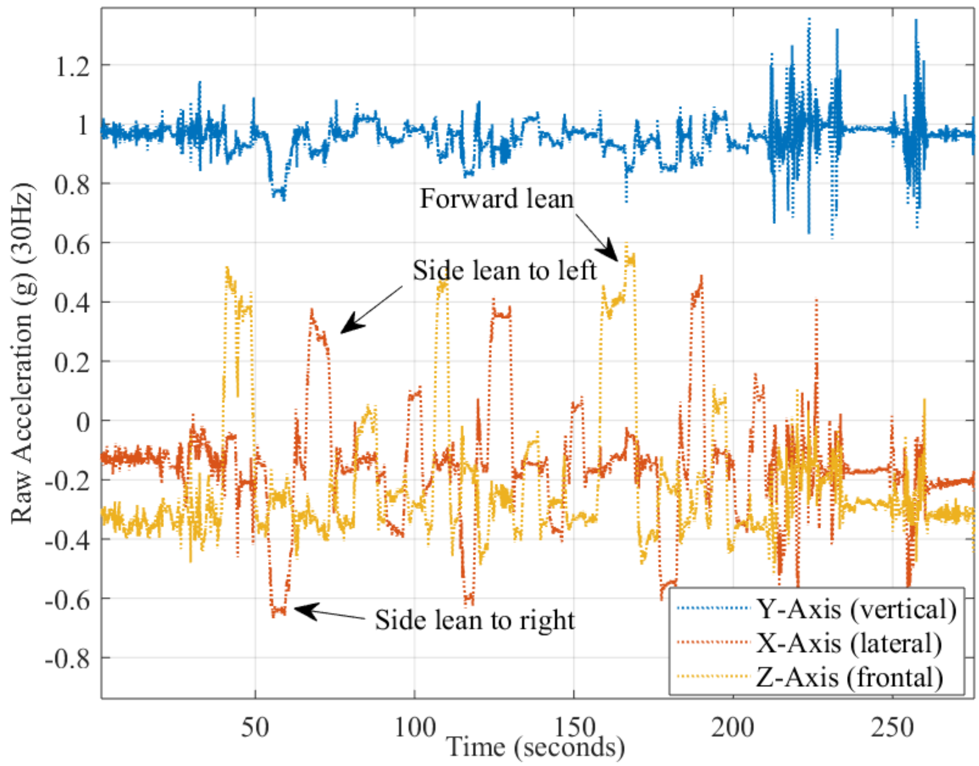

Figure 9. Raw accelerometer signal during weight shift sequence (WSS) with identifiable forward and side leans shown along x- and z-axes.

Determine non-wear time in accelerometer data. The participants were instructed to wear the accelerometer while in their wheelchairs and indicate on a daily log the time in and out of their chairs each day. Wear time assumes the participant wore the accelerometer upon getting into their wheelchair in the morning, throughout the day without removing it, and until it was removed as they got out of their chairs at the end of the day. Under this assumption, time out of the chair does not include mid-day transfers to other surfaces. The rationale for this method is that it would be almost impossible to accurately capture every transfer out of the chair. Typical mid-day transfers are to an automobile, commode, or other chair, and capturing trunk activity, and weight shifts in those sitting positions is also important. Non-wear time in this study is assumed to represent time in bed. Non-wear time will be excluded from calculations of trunk activity and weight shifts. To streamline processing of the large sets of accelerometer data, non-wear time was detected using Matlab code and compared with the daily log entries.

Through visual analysis of plotted cumulative active versus inactive periods (method will be described under trunk activity classification), it was observed that periods of inactivity of greater than approximately 75 minutes correlated with more extended periods of non-wear, typically several hours indicating sleep or rest time and also matched daily log entries for time in bed. To ensure periods of time with potential active components were not omitted, the value was increased to just over 100 minutes. This length of time is supported by studies of older individuals, sedentary, or seated subjects where it was found that non-wear cutoffs of less than 90 minutes missed inactive periods that were not non-wear (Chudyk, 2017). Automatic detection of non-wear periods was accomplished by using a classification method to detect sequences greater than 108 consecutive minutes classified as "inactive." Figure 10 provides a visualization of the non-wear periods identified in the accelerometer data using this method.

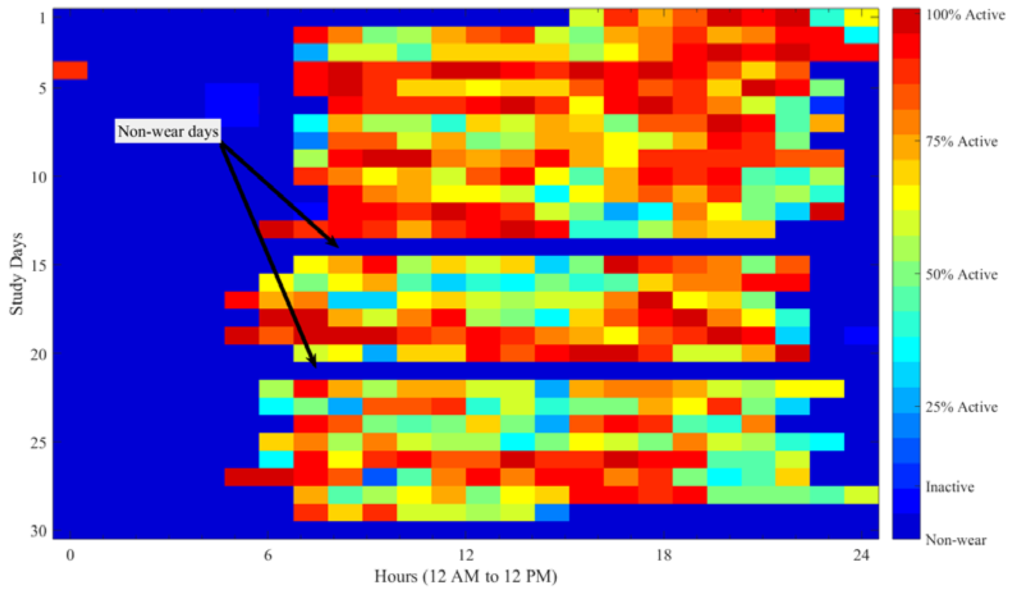

Figure 10. Non-wear time detected and shown in blue allows observation of in-chair patterns throughout the study.

Classify trunk activity. A wheelchair user's typical movements involving the trunk consist of propelling a wheelchair (by hands-on wheels or by joystick for power wheelchairs), transfers, weight shifts, reaching and other movements associated with completing typical daily activities. A classification strategy was developed to identify periods of trunk activity in the raw accelerometer data, based on known trunk activity measured during the WSS. Each participant's data was classified as active, inactive, or non-wear each day of the study period following a period of training and testing the classification method. The detailed process used for classification of the data is outlined in Appendix B and briefly summarized next.

The classification of trunk activity occurred through detection of peak to peak magnitude greater than .23g along each axis (raw data) over a 20-second window, with 50% overlap in windows. If the threshold of magnitude change along any of the three axes reached .23g, the activity was classified as active. If not, it was classified as inactive. The larger window size allowed for detection of slower trunk movements and the overlap prevented missing activity at the edges of the windows. The classification method was on average 95.34% accurate detecting trunk activity during the WSS during testing. After classifying the accelerometer signal, the daily percentage of trunk activity was calculated by dividing active time by total wear time. In figure 10 above, the percentage of active time per hour is visualized through color across the entire study period.

Classify weight shifts. Full and partial weight shifts were completed during the initial research visit, as defined in Table 2 above. While the instructions to each participant were identical, the actual movement by the participants varied due to level of injury, body habitus, or other factors. For example "lean all the way forward as far as you can" was part of the instruction for a full forward lean. Some participants had a larger tilt angle than others, even if they all leaned as far as they could. For this reason, the tilt angles needed to be examined on an individual basis to determine criteria for classifying each data point into the correct weight shift zone.

Three weight shift zones were defined by a combination of the tilt angle and the direction of movement. A detailed description of the method is available in Appendix C, and the custom Matlab code is available in Appendix D. The process is described briefly here.

First, the accelerometer data was filtered using a fifth order Butterworth low-pass filter with .25 Hz cutoff frequency. The remaining static portion of the signal was used to calculate tilt and direction angles. To develop individual thresholds for each type of weight shift, by participant, the tilt and direction angles were evaluated using data from the WSS time period. A midpoint tilt angle was calculated between peak tilt angles for full and partial forward leans, full and partial side leans, partial forward lean and baseline position, and partial side lean and baseline position. The same was calculated for power tilt users by finding the midpoint tilt angle between peak angles for full tilt and partial tilt, and between peak angles for partial tilt and baseline position.

The midpoint tilt angle between full and partial leans or full ad partial tilts was set as the lower threshold for zone 3. The midpoint tilt angle between partial leans and baseline position or partial tilts and baseline position was set as the lower threshold for zone 2. Everything below the lower threshold for zone 2 was set as zone 1 (Figures 11-14). Each participant’s time spent per day in zones 1, 2, and 3 was determined, excluding non-wear time from the calculation, resulting in a proportion value for each zone for each day of the study.

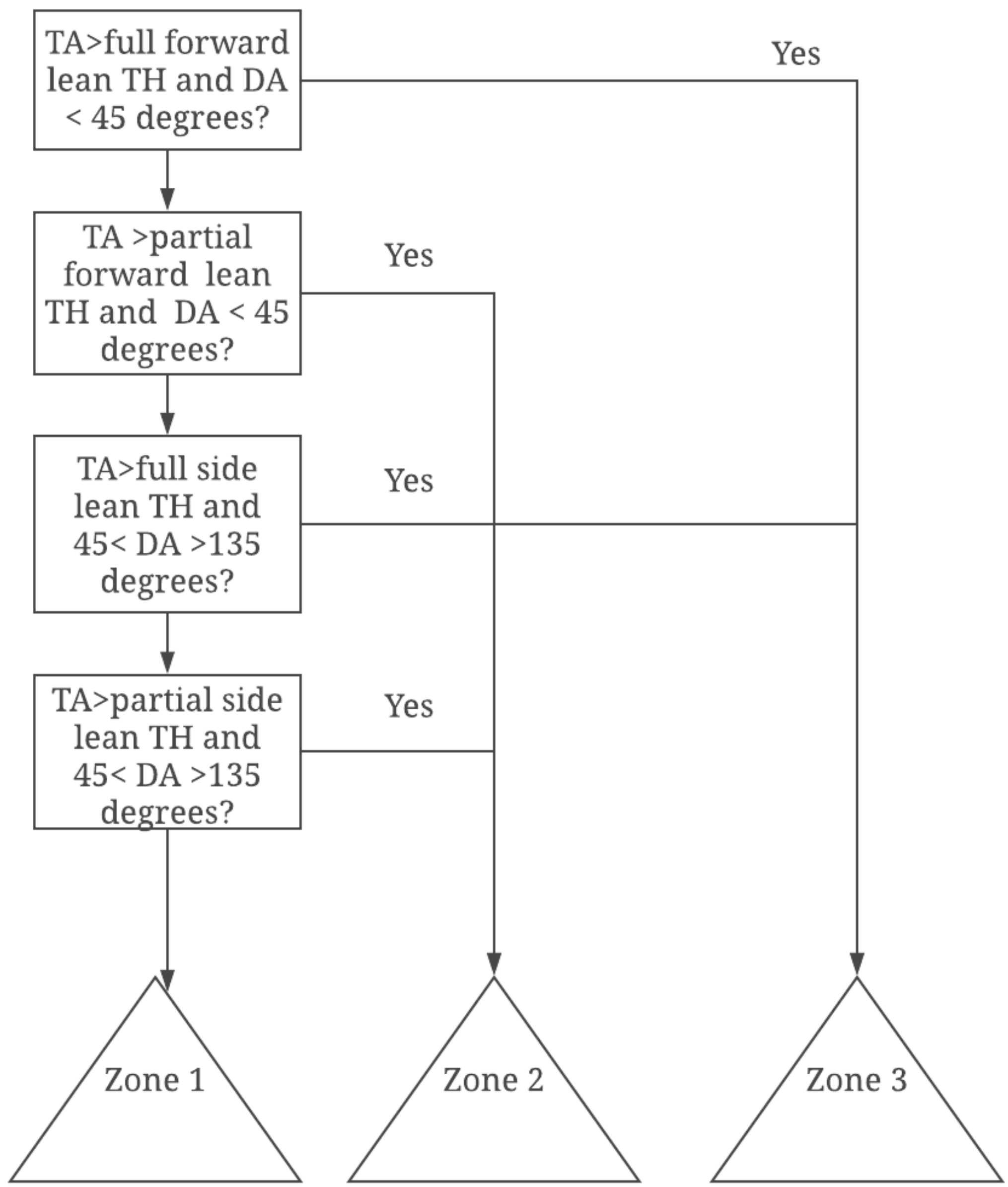

Figure 11. Process for classifying weight shift zones from tilt and direction angles for participants use leans to shift weight. TA=tilt angle; DA=direction angle; TH=thresholds determined for each participant per type of weight shift. Zone 3=full weight shifts; Zone 2 = partial weight shifts; Zone 1= Baseline positions.

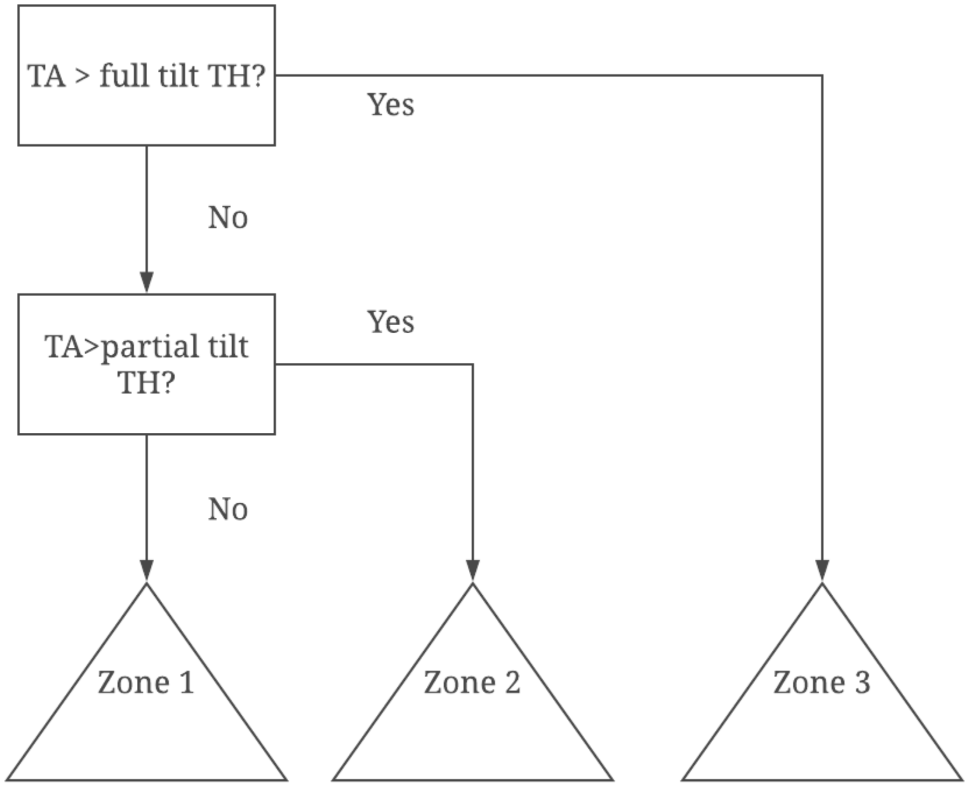

Figure 12. Process for classifying weight shift zones from tilt angles for participants who use power tilt. TA=tilt angle; TH=thresholds determined for each participant per type of weight shift. Zone 3=full weight shifts; Zone 2 = partial weight shifts; Zone 1= Baseline positions.

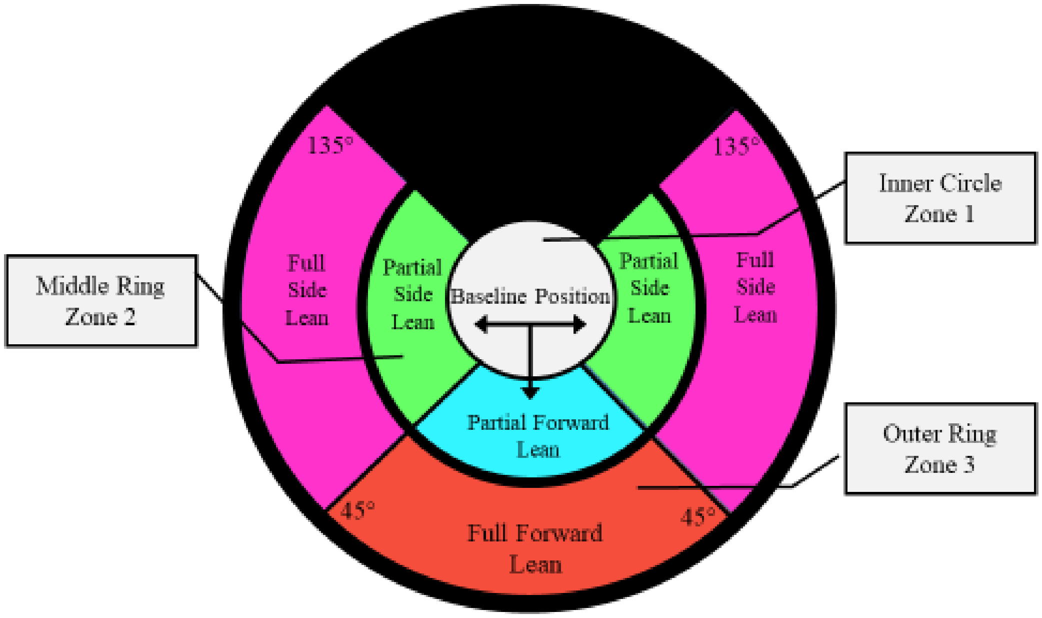

Figure 13. Manual wheelchair users (and power wheelchair users who lean vs. use power tilt) move forward or laterally to perform partial or full weight shifts. Tilt and direction angles determine if a weight shift is in zone 1, 2, or 3.

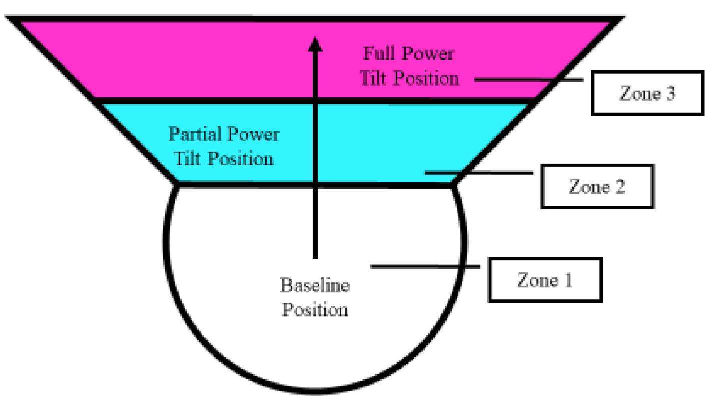

Figure 14. Participants who used power tilt moved in a posterior direction for all weight shifts. Tilt angles determined if the position was in baseline, partial tilt, or full tilt.

Self-efficacy data. Self-efficacy scores include the total score per time of administration. For statistical analysis, the primary comparisons are between SE1 and SE3 and SE2 and SE3 and then between the time points associated with map use (SE3, SE5, and SE7) versus time periods associated with not using the map (SE2, SE6, SE8). Baseline (SE1) and re-test (SE4) were not included in the map versus no map comparison.

Statistical Analysis

Descriptive Analysis. Descriptive statistics were obtained using SPSS (IBM Corp., Released 2016) frequencies and means for the demographic variables. Means and standard deviations were calculated for trunk activity and weight shifts with map use and without map use and also by groups including SCI level of injury, type of weight shift method, prior history of ulcer, and age. Self-efficacy score means and standard deviations were obtained for each of the eight repeated measures.

Inferential Statistical Analysis. For analyses, R (R Core Team, 2018)and *lme4* (Bates, Maechler, Bolker, & Walker, 2015) were used to perform linear mixed effects (LMER) analyses of the relationship between the dependent variables and pressure map use. The prediction models were built in a step-wise manner, beginning with the fitting of random effects using maximum likelihood for parameter estimation and estimation of variance components. Once optimized, the fixed effects were added, assessing the fit of the model with maximum likelihood ratio. Akaike Information Criterion (AIC) and ANOVA comparisons between models were used in the selection process.

Linear mixed-effects regression modeling will be used to test all four hypotheses. For hypothesis 1, the dependent variable is the total percent active (trunk activity) per day, the fixed effect is map use (with or without the map), and then random effects are the participants to account for their heterogeneity. The model provides an estimate of how much map use predicts change in daily trunk activity.

For hypothesis 2, the same analysis will occur for each of the three zones of weight shift as dependent variables. The fixed effect will be map use (with or without) and the random effect will be the participants.

For hypothesis 3, the model will include total self-efficacy score as the dependent variable; the fixed effect is represented by the session of administration of the scale to the participants (baseline session, post-education, and post-education plus pressure mapping as feedback). The participants are the random effects, and time is considered within the random effects since this is a repeated measure. The model will provide an estimate of the total score for each session of administration. A post-hoc test will include a planned pair-wise comparison between SE1 and SE3, and SE2 and SE3 with significance level at $\alpha = 0.05$.

Analysis related to hypothesis 4 will also use linear mixed-effect regression modeling and will use total self-efficacy score as the dependent variable, map use (with or without) as a fixed effect, and participants as random effects.

Results

Participant Characteristics

Ultimately, 25 participants met the inclusion criteria and successfully passed a cognitive screen completed the first visit of the research study. Of the 25, one did not show for the initial visit and subsequently declined further participation. The second participant failing the screen was found to have a Stage II pressure injury at the ischial tuberosity area during the initial visit's skin check and was excluded from further participation. Of the 23 who completed the initial research visit, 19 completed the home-based portion of the study. Four participants withdrew after the initial visit. The reasons for not completing the home-based portion for these four participants included a variety of issues: caregiver shortage, family emergency, discomfort from wearing the chest strap, and a fourth individual developed a small open area at right ischial tuberosity on day two. The pressure injury was described as a Stage II, < 3mm wide, and healed within five days. This skin injury was an expected potential risk and protocol was followed to monitor the participant until the area was healed. The participant was contacted by phone daily to check the status of skin until the area returned to normal. This participant had a prior history of skin problems in the same location.

Of the 19 participants who took the pressure mapping system and accelerometer home, 16 had data recorded on the accelerometer after the first day when they were seen for the research visit. This indicates that the three participants with missing data may not have worn the accelerometer as instructed during the home-based portion and thus, there was no movement data available to analyze. Of the three who did not wear the accelerometer, two completed the self-efficacy questions that were emailed or texted, yet did not wear the accelerometer. The daily logs for these two participants were 100% incomplete, but for a third, who also answered all of the self-efficacy questions, the log was detailed and complete. It is possible that there was a malfunction during data import for at least this third participant because it appears the remainder of the study protocol was followed. A flowchart of the participants and their completion of the study activities is seen in Figure 15 below.

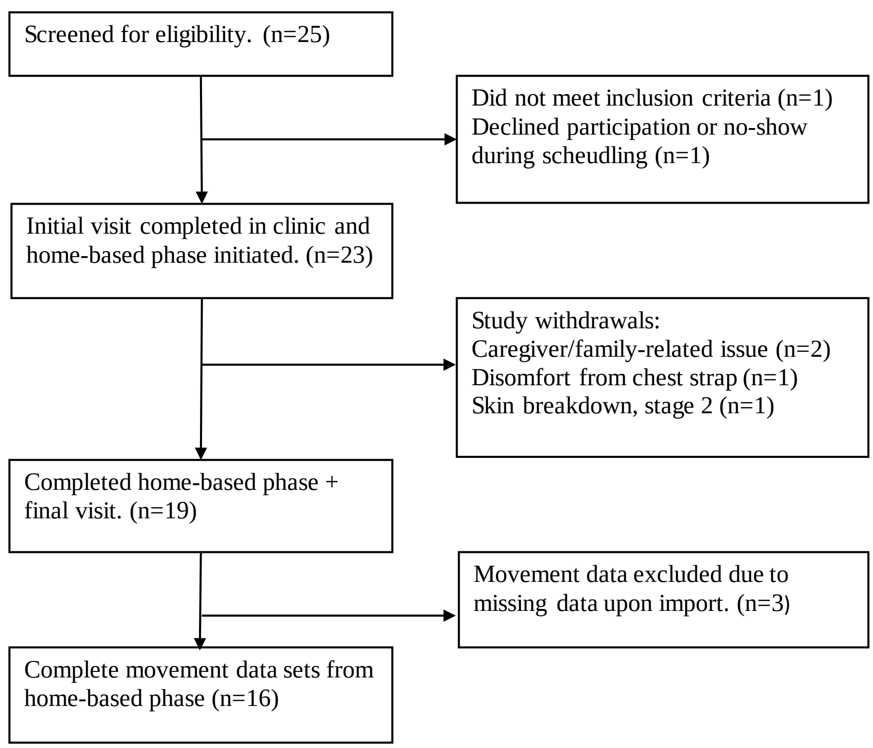

Figure 15. Flow of participants through the study.

Baseline demographics of the study participants are described in Table 7. Frequencies are reported for two groups: those who completed the initial research visit in the clinic and proceeded to start the home-based phase, and those who completed the home-based phase with intact raw data from the accelerometer. Frequency distribution of participant characteristics was similar between the two groups.

Table 7
Participants' Characteristics.

Variables	Participants At Initial Visit (N=23)	Participants Completing Home-based Phase (N=16)
Gender N (%)		
Male	18 (78.3)	11 (68.8)
Female	5 (21.7)	5 (31.3)
Level of SCI N (%)		
Cervical	10 (43.5)	6 (37.5)
Thoracic	12 (52.2)	9 (56.3)
Lumbar	1 (4.3)	1 (6.3)
Type of Wheelchair N (%)		
Manual	14 (60.9)	10 (62.5)
Power with tilt and/or recline	8 (34.8)	5 (31.3)
Power without tilt and/or recline	1 (4.3)	1 (6.3)
Type of Seat Cushion N (%)		
Offloading, non-custom	6 (26.1)	5 (31.3)
Immersion (Gel)	5 (21.7)	3 (18.8)
Immersion (Air)	9 (39.1)	7 (43.8)
Alternating air (powered)	1 (6.3)	0
Immerson (Foam)	2 (8.7)	1 (6.3)
Pressure Injury History N (%)		
Previous Skin Injury (buttocks)	11 (47.8)	9 (56.3)
Previous surgical repair (buttocks)	10 (43.5)	7 (43.8)
Time since injury N (%)		
0-5 years	7 (30.4)	3 (18.8)
6-15 years	4 (17.4)	3 (18.8)
16-30 years	10 (43.5)	8 (50.0)
>30 years	2 (8.7)	2 (12.5)
Age at time of study N (%)		
18-29 years	3 (13.0)	1 (6.3)
30-39 years	9 (39.1)	8 (50.0)
40-49 years	4 (17.4)	3 (18.8)
50-59 years	3 (13.0)	0
>59 years	4 (17.4)	4 (25.0)
Age $M \pm SD$ (range in years)	42.17 ± 13.16 (21-65)	42.5 ± 12.38 (27-63)
Years onset of SCI $M \pm SD$ (range in years)	15.74 ± 11.77 (1-43)	18.13 ± 11.40 (2-43)

Note. M = mean; *SD* = standard deviation; SCI = Spinal Cord Injury

The average study days per participant was 20.9 (SD=6.8). The number of days per phase for each participant was not equal (Table 8). Phases A1 and B1 each had averages of 6.4 (SD=1.2) and 6.6 (3.0) days respectively. Phase A2 had an average of 4.6 days (SD=3.1), and phase B2 averaged 3.3 days (SD=2.9). The pattern of fewer days in the latter phases is attributed to several factors. First, three of the participants did not complete the last two phases. One participant was hospitalized during the study before beginning phase A2. For another participant, the USB cord on the pressure map was cut accidentally before beginning phase A2. For the third participant, the accelerometer did not have usable data for the last two weeks of participation as it appeared the device was not worn. For analyses that follow, when "with map" is indicated, this includes all study days in Phase A1 and A2 and "without map" represents all study days allocated to Phase B1 and B2.

Table 8.
Study Days Allocated to Phases According to Pressure Map Use

ID	A1-First With Map Phase	B1-First Without Map Phase	A2-Second With Map Phase	B2-Second Without Map Phase	Total Days
02	7	6	6	8	27
03	4	2	0	1	7
04	7	8	5	7	27
05	5	4	5	7	21
06	9	10	4	2	25
07	7	9	0	0	16
08	5	3	0	0	8
09	7	12	9	0	28
10	5	5	7	4	21
12	6	5	5	5	21
14	7	2	4	0	13
16	6	8	7	4	25
18	7	7	7	5	26
20	7	7	7	6	27
24	7	10	0	0	17
25	6	8	8	3	25
Average Days	6.375	6.625	4.625	3.25	20.875

Note. ID=participants; A1=first with map phase; B1=first without map phase; A2=second with map phase; B2=second without map phase.

Descriptive Analyses for Trunk Movement

This section will describe the results of the analysis for trunk movement related outcomes: trunk activity and weight shifts. For all analyses, non-wear time was excluded from calculations of percentage or proportion of time per day. The rationale for this is that the duration of sitting time varied from day to day within and between participants. Distribution of trunk activity data was normal, but partial weight shift (Zone 2) and full weight shift (Zone 3) data were skewed left. Zone 1 data representing baseline position was skewed right. Practically, this pattern of distribution is realistic. It seems reasonable that a participant would assume their "typical" posture, which is represented by the baseline (Zone 1) category for propelling their chair and performing most daily activities for much of the day while Zone 2 and 3 classifications represent weight shifts.

The participants' average wear time, based on the processing of accelerometer data, was 13.6 hours ($M=13.59$, $SD=2.55$) per day. Because the participants were asked to wear the accelerometer while in their wheelchairs, this number indirectly reflects time spent in the chair. When compared with each participant's daily log entries for the self-reported time in their chair, there wasn't a significant difference between the two ($t(30)= -1.21$, $p=.23$). The daily logs were 100% complete for 11 of the 16 participants and an average of 77% complete for the remaining five participants. The least complete daily log with <50% of days filled in was for ID#08, who also had missing accelerometer data coinciding with the missing daily log data. The other four participants had one to four missing days of daily log entries. The non-wear time calculated from the accelerometer data was not significantly different from the daily logs, so it was used in the calculations that follow to determine the percent of time per day in the different types of trunk movements.

Descriptive analysis of trunk activity. Mean trunk activity across all participants per day was 47.8% (SD=20.2) when using the pressure mapping system compared to 47% of the day (SD=19.6) when not using the pressure map, resulting in a small increase of .8% when using the pressure map (Table 9).

Table 9.
Mean Trunk Activity With and Without Map Use

			95% CI	
% per Day	*M*	*SD*	*LL*	*UL*
Activity				
With Map	0.478	0.202	0.448	0.508
Without Map	0.47	0.196	0.439	0.501

Note. CI = confidence interval; *LL* = lower limit; *UL* =upper limit.

There was variability between participants for trunk activity (Figure 16). Specific covariates could have influenced movement patterns between participants. Means for trunk activity were calculated for with map and without map conditions for the following covariates: level of injury, age, weight shift method, and history of prior pressure injury to learn about how they may have impacted the variability between participants. Individuals with a thoracic level injury, those who lean to weight shifts, and those under 40 tended to have higher trunk activity values for both with and without mapping conditions (Figures 17-19). Trunk activity was just slightly higher for individuals with a prior pressure injury than those without a prior ulcer (Figure 20). Participants with a cervical level injury, who use power tilt as a weight shift method, and are over age 40 appear to have had a decrease in trunk activity with the pressure map use (Figures 18-20).

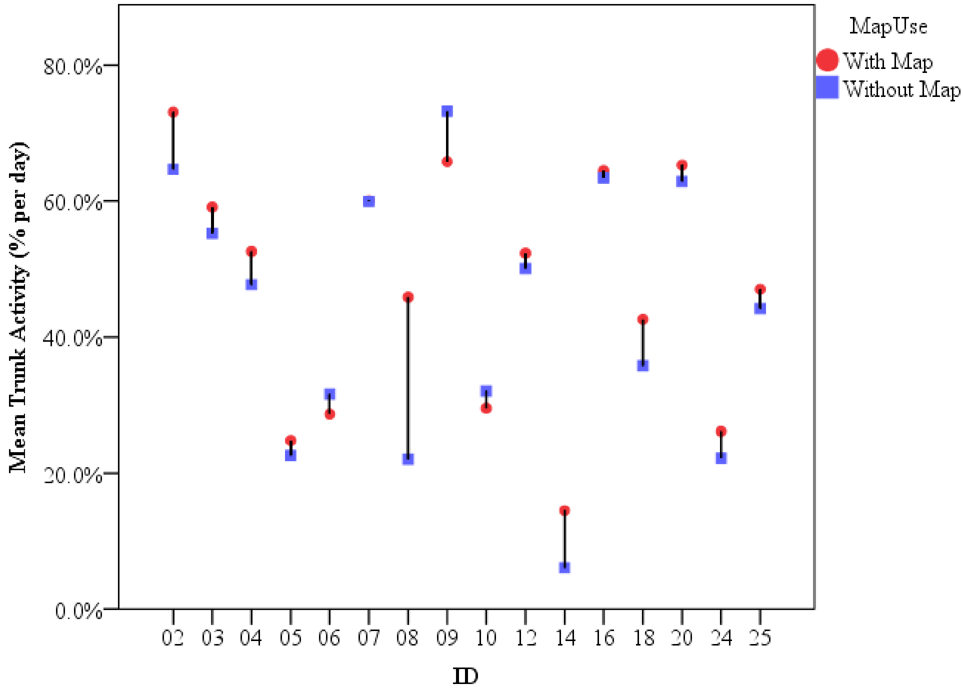

Figure 16. Participant level mean trunk activity based on map use.

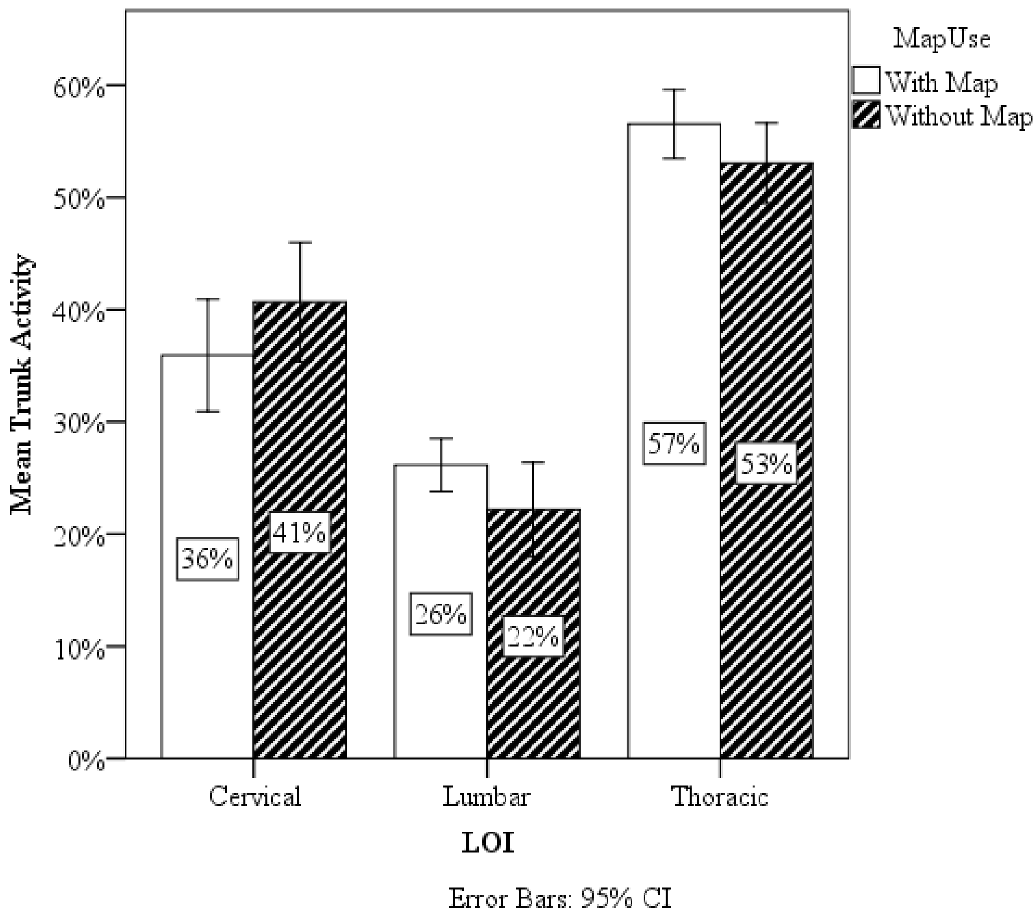

Figure 17. Comparison of mean trunk activity based on level of injury (LOI).

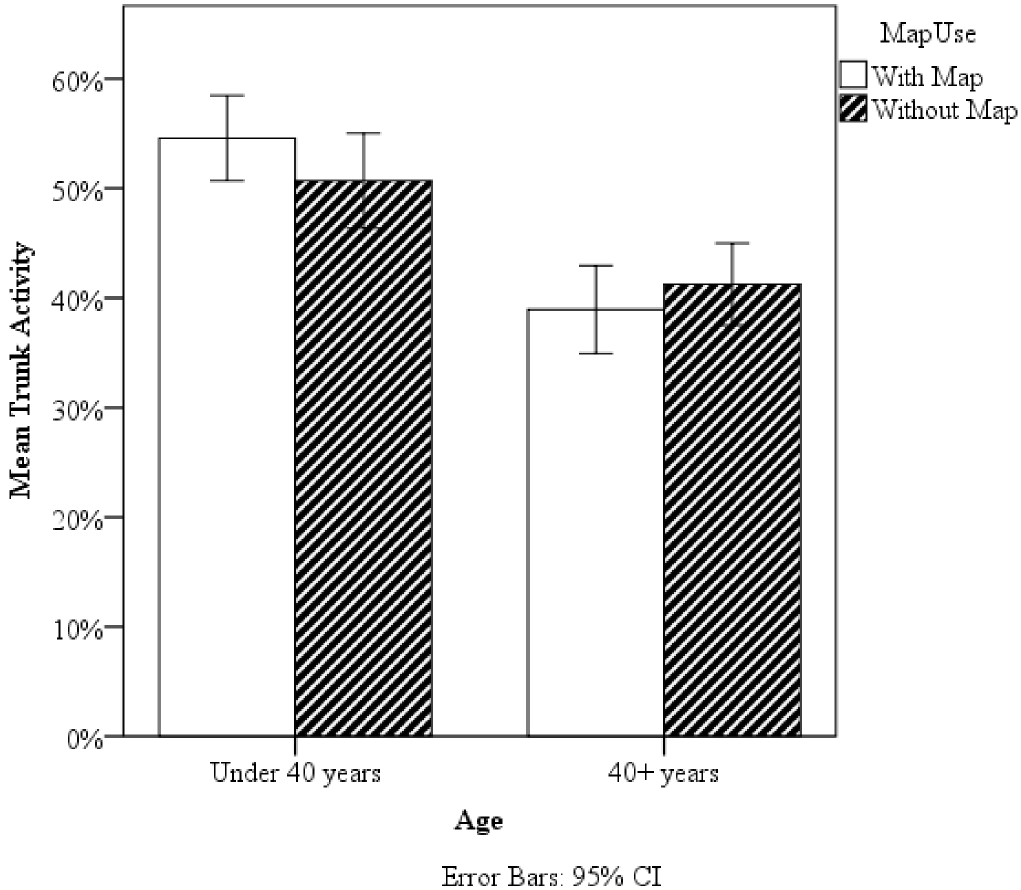

Figure 18. Comparison of mean trunk activity based on age.

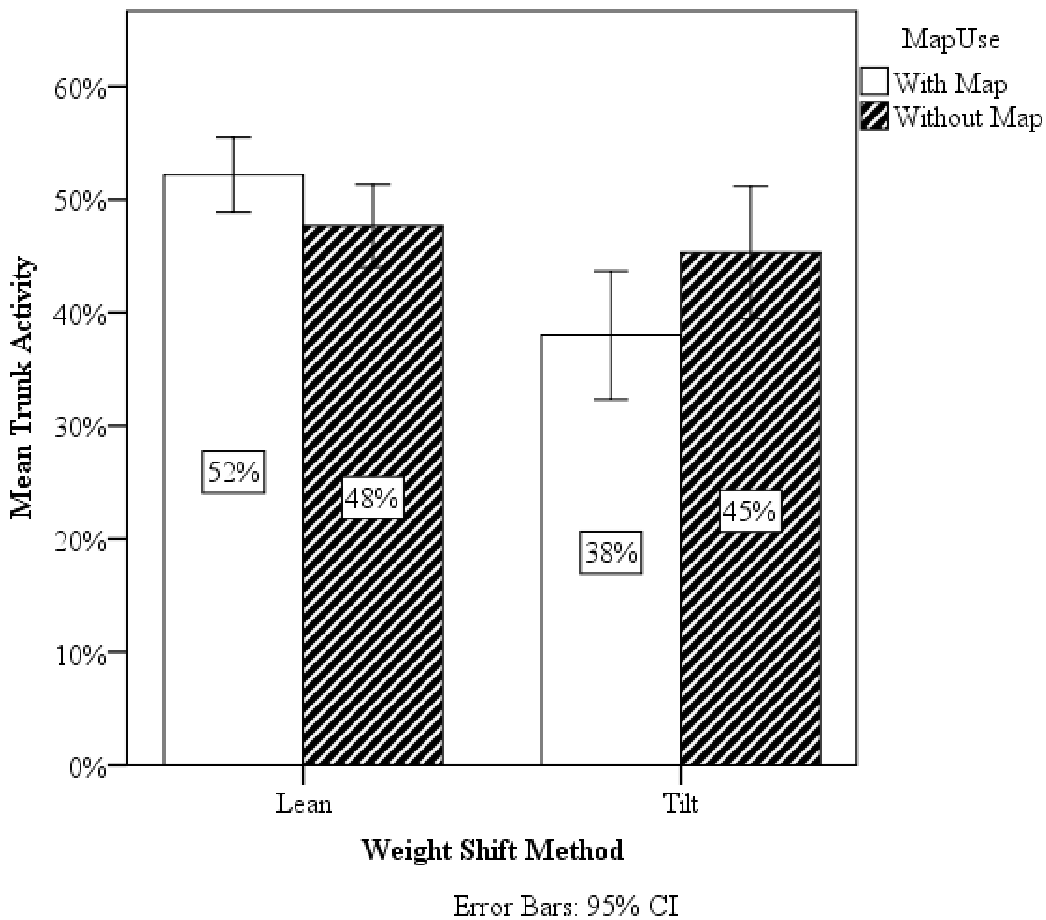

Figure 19. Comparison of mean trunk activity based on weight shift method.

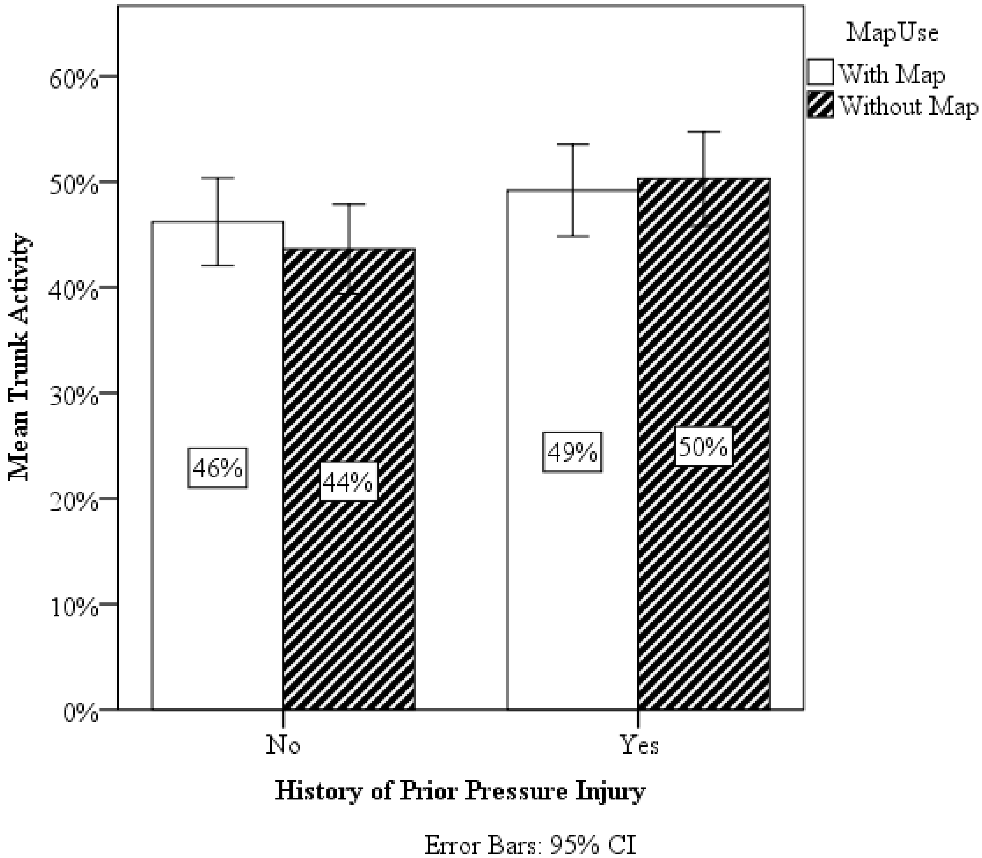

Figure 20. Comparison of mean trunk activity based on history of prior pressure injury.

Descriptive analysis of weight shifts. Mean time across all participants spent in full weight shift positions increased from 12% (SD=15.6) to 12.7% (SD=18.1), and for partial weight shift positions from 9.3% (SD=13.9) to 9.7% (SD=14.4). Conversely, the mean time spent in baseline postures decreased from 78.7% (SD=21.2) to 77.6% (SE=22.1) (Table 10) and depicted in pie charts in Figure 21.

Table 10.
Means with Confidence Intervals and Standard Deviations of Weight Shifts Proportions With and Without Map Use

	With Map[a]				Without Map[b]			
			95% CI				95% CI	
% per Day	*M*	*SD*	*LL*	*UL*	*M*	*SD*	*LL*	*UL*
Zone 1	0.776	0.221	0.743	0.809	0.787	0.212	0.753	0.82
Zone 2	0.097	0.144	0.075	0.118	0.093	0.139	0.071	0.115
Zone 3	0.127	0.181	0.1	0.154	0.12	0.156	0.096	0.145

Note. *CI* = confidence interval; *LL* = lower limit; *UL* =upper limit; Zone 1 = Baseline osition; Zone 2 = Partial weight shifts; Zone 3 = Full weight shifts.
[a]n = 176; [b]n =157.

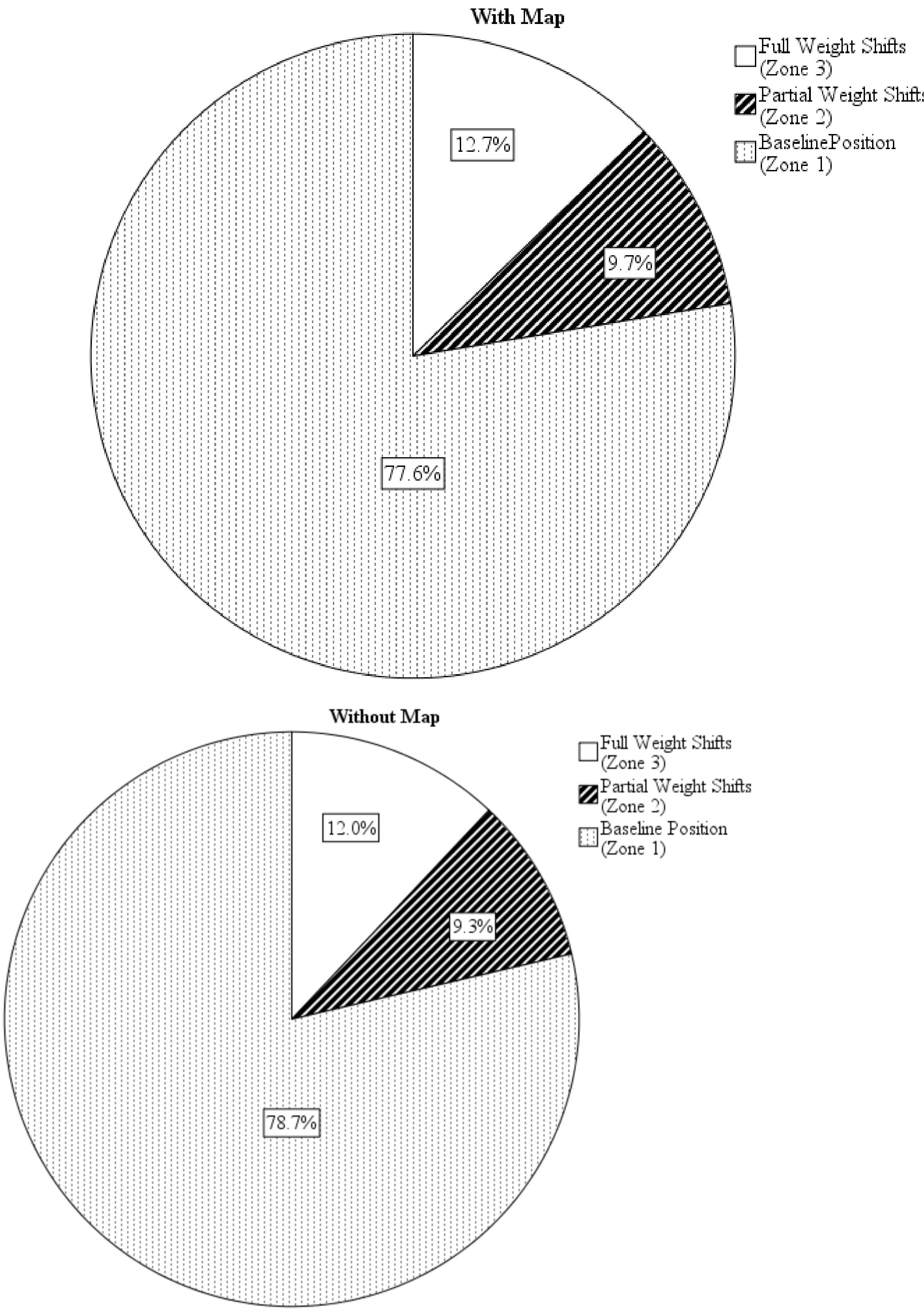

Figure 21. Mean proportion of day spent in each type of weight shift position with and without map use.

Figures 22, 23 and 27 below show the small changes in time spent in each weight shift zone at the participant level, based on map use. Participants 8 and 14 had the most change with pressure map use. However, their results should be interpreted with caution because both had fewer than 15 study days and both had three or fewer total study days in the non-mapping phase. Covariates and distribution of time spent in partial and full weight shifts were explored and can be seen in the bar charts in Figures 24-26 and 28-30. Observations worth noting include the appearance of increased time spent in partial weight shifts (Zone 2) for those with lumbar level injuries. There was only one participant with a lumbar level injury. Overall, time spent in partial weight shift positions tended to be slightly higher for those with cervical level injuries (if not considering the lumbar level injury), over 40, and prior history of a pressure injury. For full weight shifts (Zone 3), the pattern was different with more time spent in full weight shifts by individuals with thoracic level injuries and under 40. Similar to the results for partial weight shifts, more time in full weight shifts was associated with a previous pressure injury

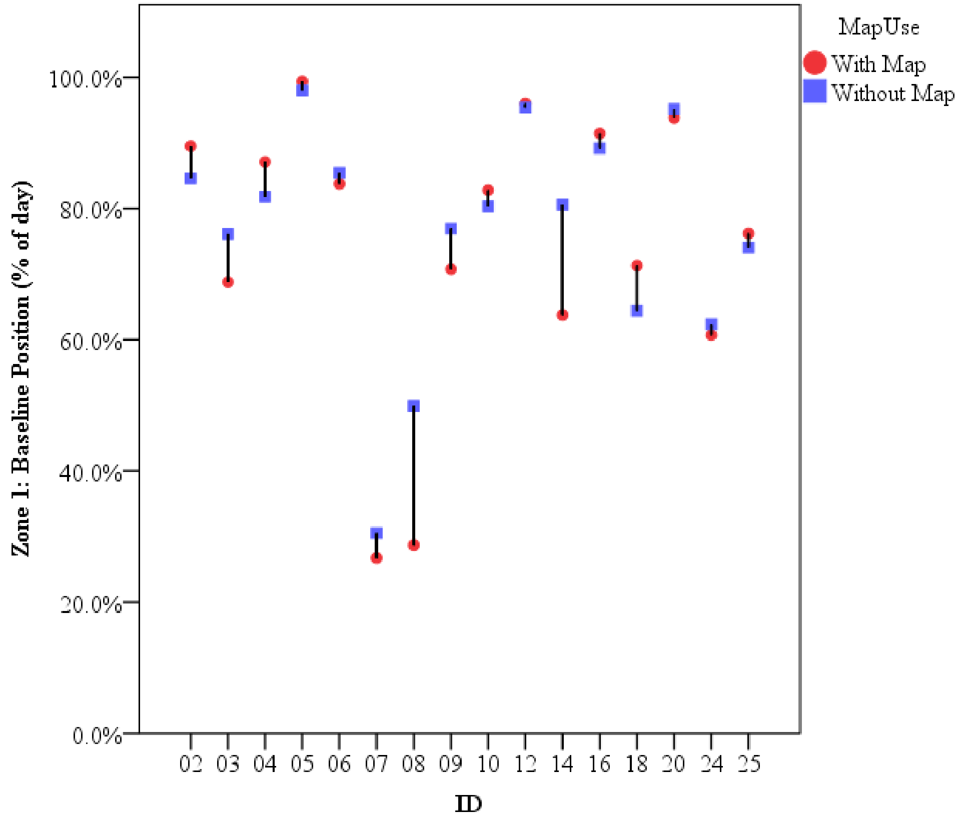

Figure 22. Proportion of day spent in the typical or baseline position by each participant.

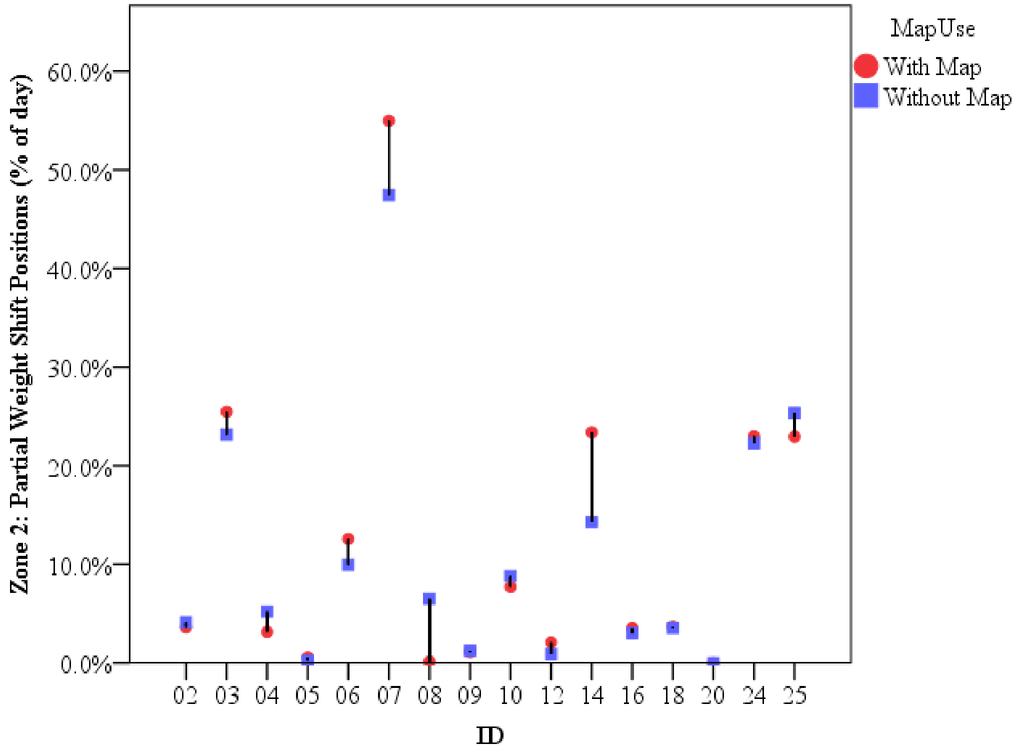

Figure 23. Proportion of time per day spent in partial weights shift positions by each participant.

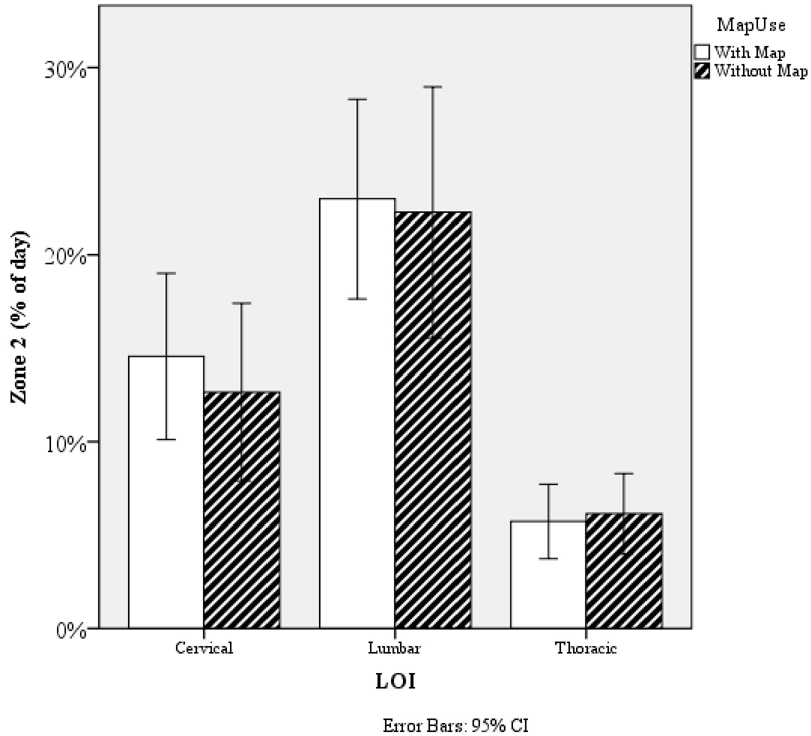

Figure 24. Comparison of time spent in partial weight shift positions (Zone 2) based on level of spinal cord injury.

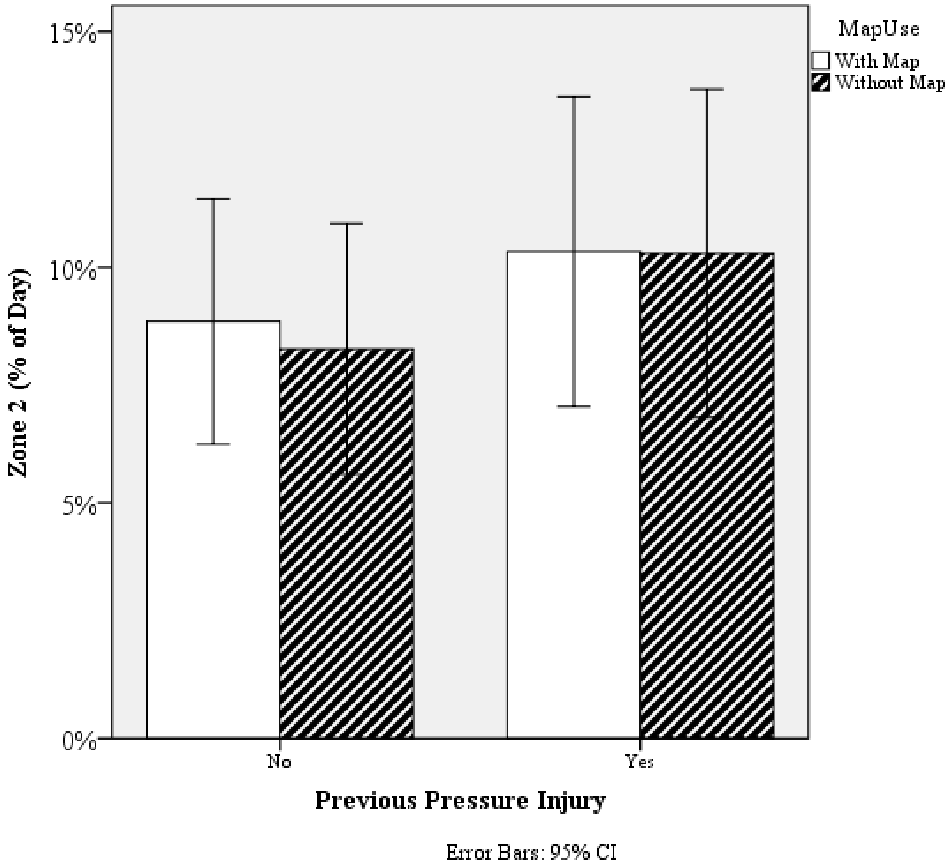

Figure 25. Comparison of time spent in partial weight shift positions (Zone 2) based on level of presence of a previous pressure injury.

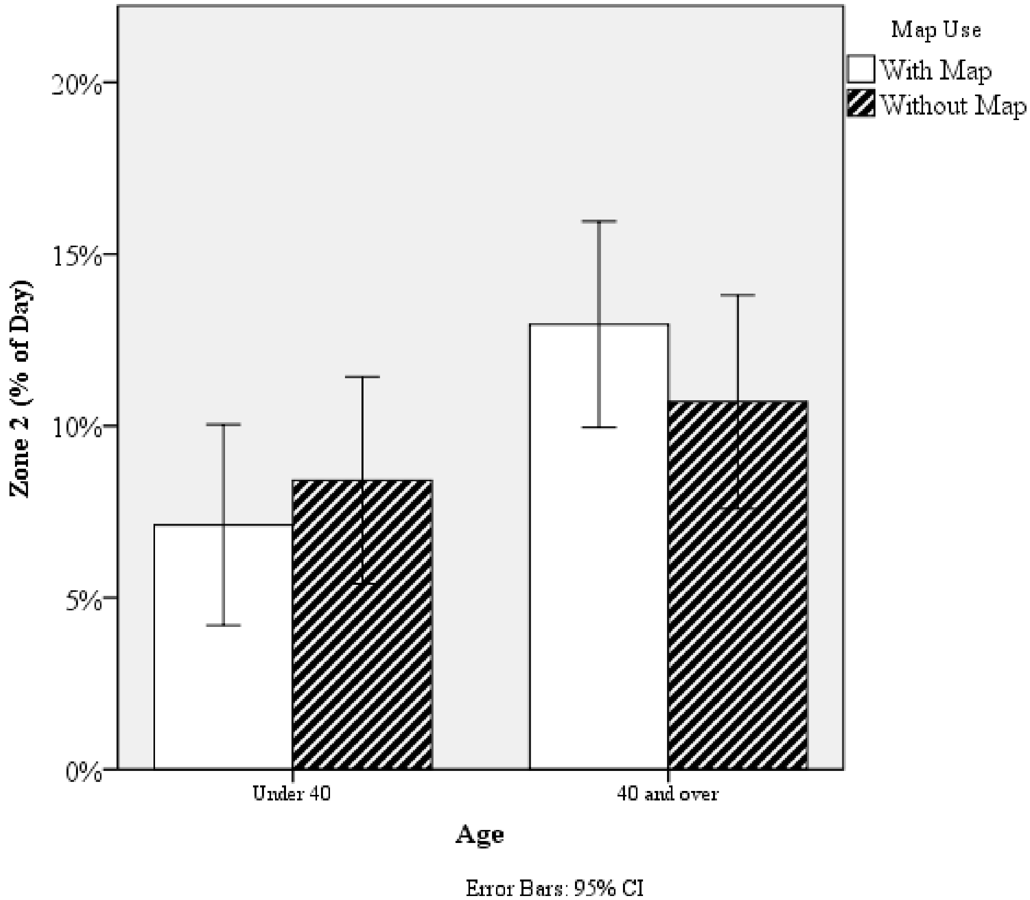

Figure 26. Comparison of time spent in partial weight shift positions (Zone 2) based on age.

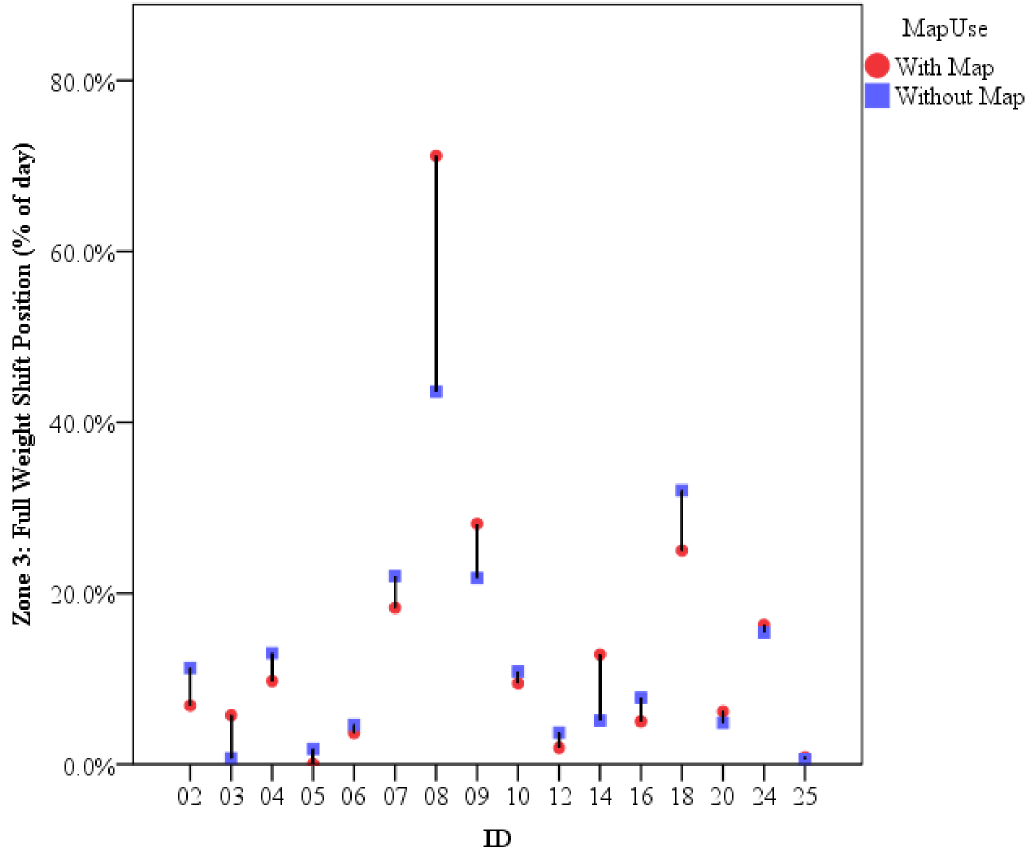

Figure 27. Proportion of day spent in full weight shift positions by each participant.

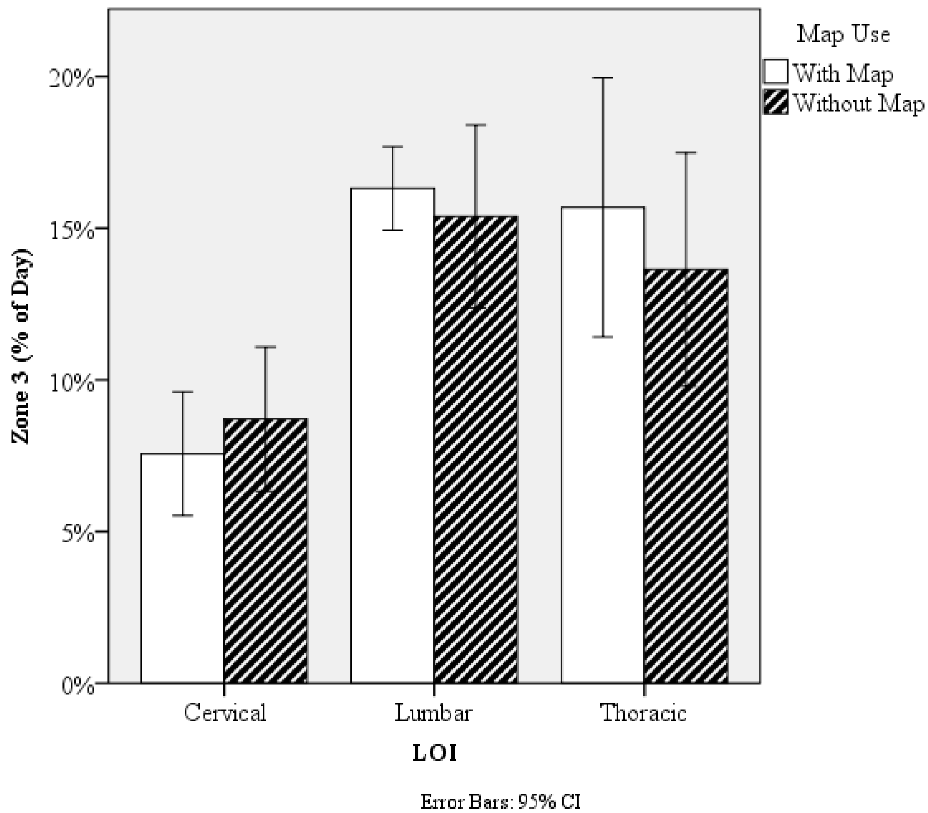

Figure 28. Comparison of time spent in full weight shift positions (Zone 3) based on level of spinal cord injury.

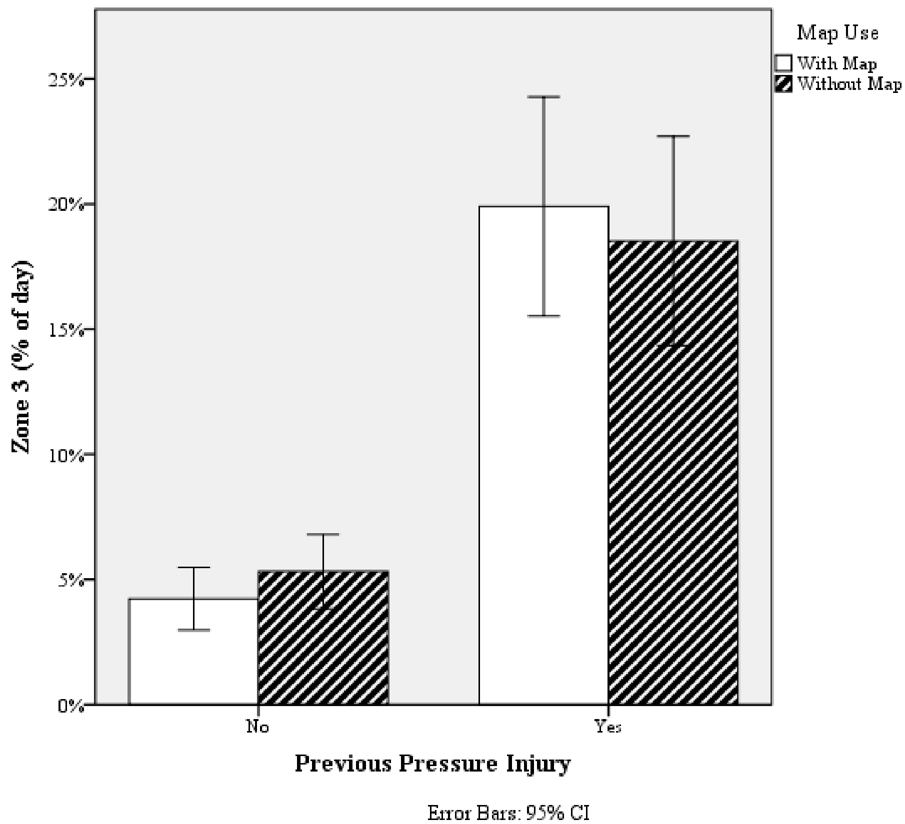

Figure 29. Comparison of time spent in full weight shift positions (Zone 3) based on history of previous pressure injury.

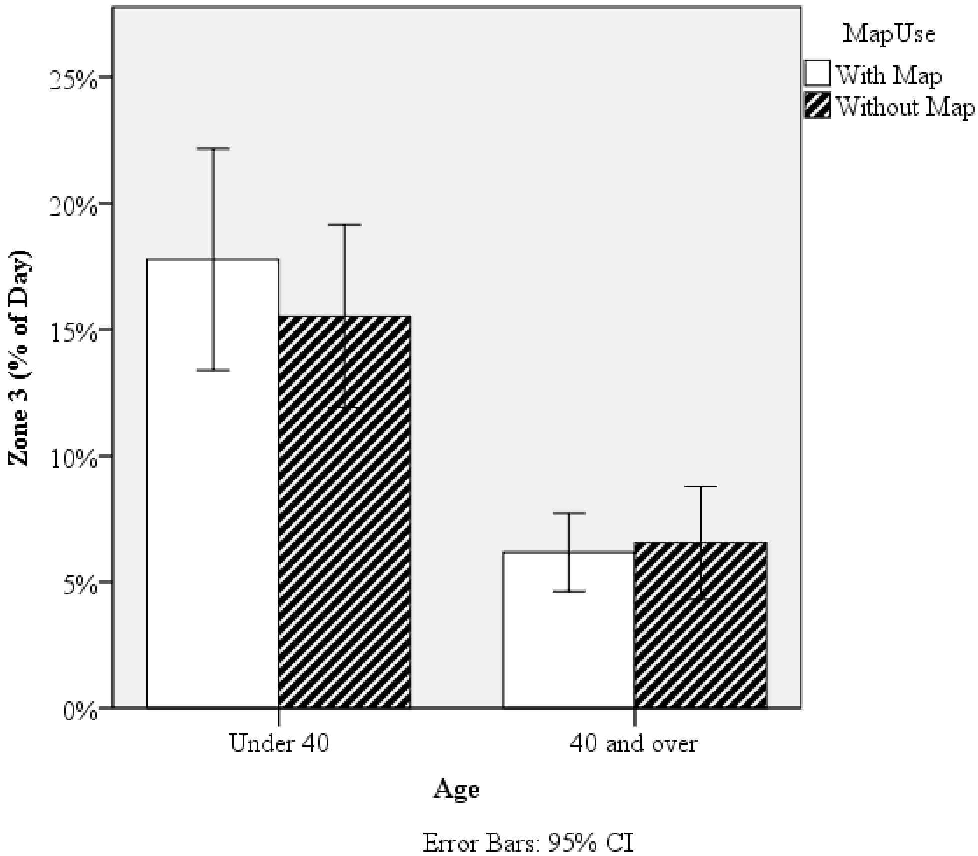

Figure 30. Comparison of time spent in full weight shift positions (Zone 3) based on age.

Summary of descriptive analyses for trunk activity and weight shifts. For a more comprehensive understanding of how each participant moved while using the pressure map versus when not using the pressure map, it was helpful to observe the descriptive information for all of the movement-related variables together, and specifically the patterns of change that occurred with map use compared to without map use by individual. For each participant, a value was calculated to show how much their movement changed when the pressure map was used versus when it wasn’t used. The changes in trunk activity and weight shift positions are displayed in Table 11. The amount of time in minutes that each change translated to, for each participant was calculated using Equation 1. Individualization, based on each participant's average time in chair each day, provided a practical perspective on how meaningful the change between conditions was for each participant.

(1) (% With Map – % Without Map) x Hours in Chair x 60 = minutes in activity

An example is provided to clarify what the values in this table represent. For participant ID #02, trunk activity with map use was 73.1% of the day and without map use, 64.7% of the day. In Table 11, the value 8.4% represents the difference between these values. If positive, then trunk activity increased with map use, and if negative, there was a decrease in trunk activity with map use. An 8.4% increase in trunk activity, when spending an average of 15.1 hours/day in-chair equates to 76.1 minutes of increased trunk activity per day for ID#2 when they used the pressure map.

Overall, in this study, thirteen of the sixteen participants (81%) experienced an increase in trunk activity during periods when the pressure map was used. There were positive changes in weight shift behaviors as well. Ten of the participants had increased time in Zone 2, and seven had increased time in Zone 3. An increase in either Zone 2 or 3 weight shift zones was observed in 81.2% of the participants. There was variability in how much change occurred. Some individuals, such as ID #2, had a larger increase in activity with pressure map use. ID#2 spent an average of 15 hours/day in chair. The 8% increase in activity experienced by ID#2 translates to an additional 72 minutes of activity per day with map use.

Table 11.

Difference in Trunk Activity and Weight Shift Percentage of Day with Map Use

ID	Hours in Chair	Trunk Activity	Zone 1: Baseline	Zone 2: Partial Weight Shift	Zone 3: Full Weight Shift
2	15.1	8.40%	4.91%	-0.50%	-4.40%
3	12.6	3.87%	-7.35%	2.31%	5.04%
4	11.4	4.91%	5.32%	-2.05%	-3.27%
5	14	2.21%	1.38%	0.33%	-1.71%
6	13.7	-2.93%	-1.67%	2.62%	-0.95%
7	13.2	0.11%	-3.79%	7.52%	-3.73%
8	11.3	23.81%	-21.23%	-6.37%	27.60%
9	14.3	-7.41%	-6.21%	-0.13%	6.34%
10	10.5	-2.50%	2.46%	-1.09%	-1.37%
12	13.3	2.28%	0.60%	1.18%	-1.79%
14	10.9	8.41%	-16.83%	9.10%	7.72%
16	12.3	1.04%	2.25%	0.53%	-2.77%
18	13.1*	6.83%	6.90%	0.13%	-7.03%
20	13.4	2.40%	-1.34%	0.00%	1.34%
24	14.3	3.97%	-1.64%	0.71%	0.92%
25	14.9	2.83%	2.16%	-2.40%	0.24%

Note. Positive values for trunk activity, zone 2 and zone 3 indicate positive change with map use. Negative values indicate trunk activity and time spent in partial and full weight shifts decreased with map use. Zone 1= Baseline position; Zone 2=Partial weight shifts; Zone 3=Full weight shifts.

Exploration of movement data also included breaking the trunk activity and weight shift data down by the four phases of map use for each of the four trunk movement variables. Means and standard deviations for the four variables of trunk movement (trunk activity and weight shifts) by phase are provided in Table 12. Trunk activity was highest in the first mapping phase (M=0.48, SD=.21) and lowest in the final phase, B2, a non-mapping phase (M=.46, SD=.20). The differences in time spent in weight shift positions between the individual phases does not appear to follow a particular pattern.

Table 12

Mean Trunk Movement (Trunk Activity and Weight Shifts) Across Each Phase

Day	% per	A1a				B1b			
				95% CI				95% CI	
		M	*SD*	*LL*	*UL*	*M*	*SD*	*LL*	*UL*
	Activity	0.484	0.207	0.443	0.524	0.48	0.196	0.437	0.513
	Zone 1	0.77	0.228	0.725	0.815	0.76	0.222	0.712	0.798
	Zone 2	0.114	0.158	0.083	0.145	0.12	0.159	0.088	0.15
	Zone 3	0.117	0.165	0.084	0.149	0.13	0.149	0.097	0.155
		A2c				B2d			
				95% CI				95% CI	
Day	% per	*M*	*SD*	*LL*	*UL*	*M*	*SD*	*LL*	*UL*
	Activity	0.471	0.197	0.425	0.517	0.46	0.197	0.407	0.516
	Zone 1	0.785	0.213	0.736	0.834	0.85	0.176	0.799	0.896
	Zone 2	0.073	0.119	0.046	0.101	0.04	0.062	0.025	0.059
	Zone 3	0.142	0.201	0.096	0.188	0.11	0.169	0.063	0.157

Note. CI = confidence interval; LL = lower limit; UL =upper limit. A1 and A2 = Map used; B1 and B2 = No Map.

[a] n = 102. [b]n = 104. [c]n = 75. [d]n = 53.

During the final visit, participants were asked if they had feedback or comments about their experience using the pressure mapping system at home (Table 13).

Table 13

Participant Comments about Their Experience Using the Mobile Pressure Map at Home

ID	Participant Comments
2	"Doesn't take much movement at all to relieve pressure!"
3	"I could see that I was relieving pressure when I leaned and looked at the map. I was more aware of pressure when using the map. I saw a lot of red along one side and couldn't make it better with repositioning. As a result, I made an appointment with seating clinic."
4	"Having the mat helped me be more aware of the need to move. I tried to do lifts more often. I used my cell phone's timer to hold them for full minute. But my arms got tired."
5	"I don't really do anything to relieve pressure during the day. May use map more as I get older because I know skin changes over time. So far, I've been lucky."
6	"I'm more conscious of pressure when using the mapping system. I use tilt more when using the mat because I'm way more conscious of pressure."
7	
8	"Could see differences on map if I changed something. I thought about moving more when I could see the map. I was able to investigate a problem with my cushion and make an appointment to have it checked. This proves how useful it is to have."
9	"Found the map helpful. When I saw red, I got wigglier in my chair and pressure got better."
10	"You can see the pressure, so you're moving more. It reminded me to move."
12	
14	
16	
18	
20	
24	
25	"I found the ability to see my pressure very helpful. I learned I could lean back just slightly and get pressure off my tailbone and that when I lean forward, I completely offload my IT's"

Inferential Statistical Analyses of Trunk Movement

To control for individual differences in movement patterns, linear mixed-effects regression modeling was used to analyze trunk activity and weight shift based on map use. The models for each of the four dependent trunk movement variables included participants as random effects and use of the pressure map as a fixed effect (Table 14). Visual inspection of residual plots did not reveal any apparent deviations from homoscedasticity of normality except for the residual plot for partial weight shift data. The residual distribution for the Zone 2 data had heavy tails, so results should be interpreted with the understanding that the raw data was heavily skewed left. Kenward-Roger approximation of degrees of freedom was used to evaluate the significance of differences in fixed effects.

For each of the four final models (Table 14), between 59-78% of the variation in trunk activity and weight shifts were attributed to the heterogeneity of the participants. Controlling for this variation when comparing the response of the dependent variables to the fixed-effect is the primary rationale for using the mixed-effect method.

Table 14.
Prediction Models for Trunk Movement Variables Based On Pressure Map Use

	Model 1: Percent Active	Model 2: Baseline Position	Model 3: Partial Shifts	Model 4: Full Shifts
	Fixed effects			
Intercept: Map β (SE)	0.47 (.045)	.749 (.005)	0.116 (0.035)	.0135 (.0038)
Map Use: No Map β (SE)	-0.026 (0.012)	.0002 (.002)	-0.003 (0.008)	.00009 (.001)
p-value	**0.03***	0.890	0.7	0.95
	Random effects			
Participant				
Variance (SD)	0.03 (0.18)	0.04 (0.195)	0.019 (0.138)	0.022 (0.15)
Residual				
Variance (SD)	0.011 (0.11)	0.018 (0.135)	0.005 (0.07)	0.014 (0.12)
ICC_{ID}	0.73	0.66	0.78	0.593

Note. Significance codes: 0.001 '***', 0.01 '**', 0.05 ‘*’.

Inferential analyses of trunk activity. After controlling for participant variations, there is a small but statistically significant difference in trunk activity between with map and without map conditions. The model estimates that 47% of day was active with map versus 44% without map (β= 0.47, SE=0.05, t=-2.186, ICC=.73, p=.030). This translates to an average of 25 more active minutes per day when the pressure map was used (based on an average of 13.6 hours/day estimated time participants in this study spent in their wheelchairs) (Figure 31). This result reached the level of significance, α=.05; thus, the null hypothesis is rejected, and it is inferred that trunk activity increases when using a pressure map for visual feedback.

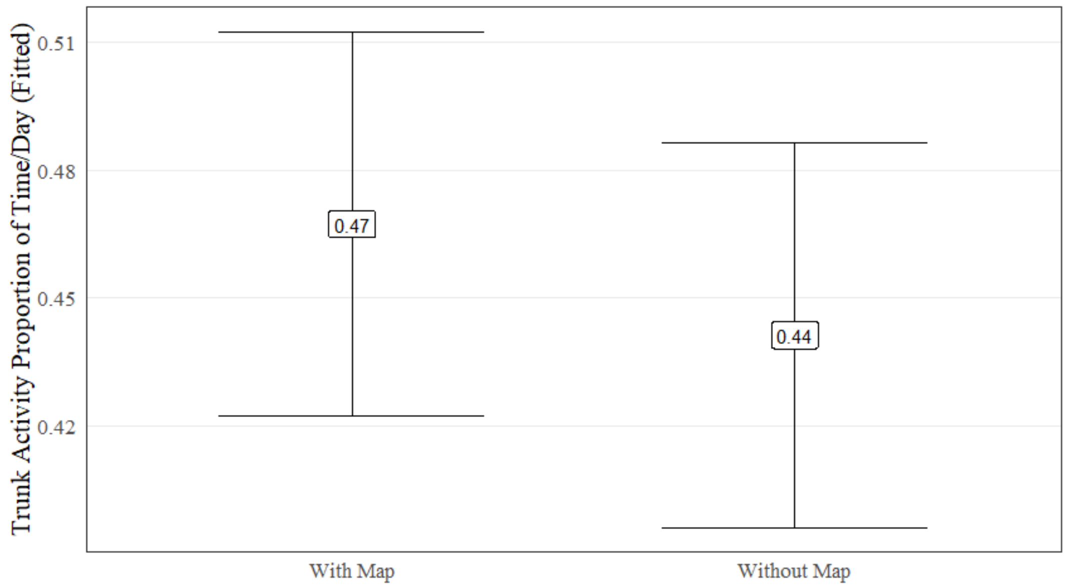

Figure 31. Estimates for the percentage of day of trunk activity, based on the use of map in the field after adjusting for differences between participants in the prediction model. (Value multiplied by 100 provides % of day active).

Inferential analyses for weight shifts. Sixty-six percent of total variability in the proportion of time spent in a baseline posture was due to participant differences. Controlling for participant differences, it was predicted that time spent in Zone 1 without using the pressure map was just slightly higher (β=.0002, SE=.002, t=.141, ICC= .66, p=.89) than when the map is used (Table 14, Model 2). The value .0002 represents .02% of a day, or a total of about 30 seconds different per day, which regarding the typical resting or functional position, does not have significant implications. The difference did not reach the level of significance, α=.05, so the null hypothesis was not rejected.

Seventy-eight percent of total variability in proportion of time spent in a partial weight shift posture was due to participant differences. Controlling for that difference, it was predicted that time spent in Zone 2 was barely lower when not using the pressure map (β=-.003, SE=.008, t=-.388, ICC= .78, p=.70) than when the map is used (Table 14, Model 3). The difference did not reach the level of significance, α=.05, so the null hypothesis is not rejected.

Fifty-nine percent of total variability in proportion of time spent in a full weight shift position was due to participant differences. Controlling for that difference, it was predicted that time spent in Zone 3 while using the pressure map was unchanged (β=.00009, SE=.001, t=.07, ICC= .59, p=.95) than when the map is not used (Table 14, Model 4). The difference did not reach the level of significance, α=.05, so the null hypothesis is not rejected.

In summary, trunk movement results reached significance for Hypothesis 1 for trunk activity. Results did not reach significant level for weight shifts (Hypothesis 2).

Analyses of Self-efficacy Data

Descriptive analyses of self-efficacy data. Mean and standard deviations for total self-efficacy score and each self-efficacy question scores are reported in Table 15. The range of possible scores was 0-100. One participant had a score of zero for all four baseline questions. The means shown and the analyses that follow include that score even though it is an outlier. The rationale for not removing the score is that while the participant's score is dramatically lower, it reflects beliefs before receiving education and the scores were in line with the other participants for each of the remaining tests.

Table 15
Mean and Standard Deviation (SD) for Each Administration of the Self-efficacy Questions

	Total Score	Q1. Prevention Overall	Q2. Effective in Movement	Q3. Frequency of Movement	Q4. Duration of Movement
Time	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*
SE1	84.1(21.4)	85.2(23.7)	79.8(25.8)	82.3(28.8)	88.9(25.0)
SE2	89.5(11.1)	90.2(14.2)	85.7(17.7)	89.8(20.1)	92.4(16.5)
SE3	93.7(8.8)	94.3(9.9)	97.0(5.6)	91.5(16.9)	92.0(16.7)
SE4	95.3(7.9)	94.5(10.1)	97.6(4.2)	94.7(10.2)	94.2(10.2)
SE5	95.0(8.4)	93.8(9.9)	95.3(8.9)	95.0(10.5)	95.9(9.2)
SE6	92.2(9.8)	93.8(9.4)	91.9(11.8)	89.7(15.6)	93.4(9.8)
SE7	95.3(8.4)	96.2(7.7)	97.3(6.0)	95.4(9.7)	92.3(13.6)
SE8	93.5(10.1)	95.9(7.4)	95.0(8.7)	91.8(12.5)	91.4(14.2)

Note. *CI* = confidence interval; *LL* = lower limit; *UL* =upper limit. SE1 = Baseline; SE2 = Post-Education; SE3 = Education + Map; SE4 = Test-Retest; SE5 & SE7 = Map; SE6 & SE8 = No Map.

Mean total score increased from baseline (M=84.1, SD=21.4) to post-education via standard clinical guidelines (M=89.5, SD=11.1) and increased again following use of the pressure map to guide weight shift maneuvers (M=93.7, SD=8.8). The mean self-efficacy total scores reflect a ceiling effect, with scores overall clustered toward higher end of scale. Overall, though, the scores changed in the predicted direction. Mean scores increased with education and increased further with use of map as feedback and were higher during phases that included pressure map use. The number of missing scores increases through time, with N=23 at start and N=12 by the last time the questions were presented to the participants, reflecting the drop-outs/withdrawals from the study after the initial visit, as well as the lack of response from some participants as time passed.

The most considerable change in score occurred on the self-efficacy scale over time and specifically from SE2 to SE3 was for question 2 (Figure 32). Question 2 asked the participant about their belief that they could move far enough to redistribute pressure on their sitting surface. Question 2 scores are highest when asked during periods that included pressure map use.

A Spearman's rank correlation coefficient was computed to assess repeatability of the self-efficacy questions used in this study. The test-retest correlation between SE3 and SE4 was $r_s(19)=.71$, $p=.001$. Face validity was verified by sharing the questions with spinal cord injury occupational and physical therapists and seating and mobility experts at Mayo Clinic who work in the seating clinic and have experience working specifically with individuals who have spinal cord injuries.

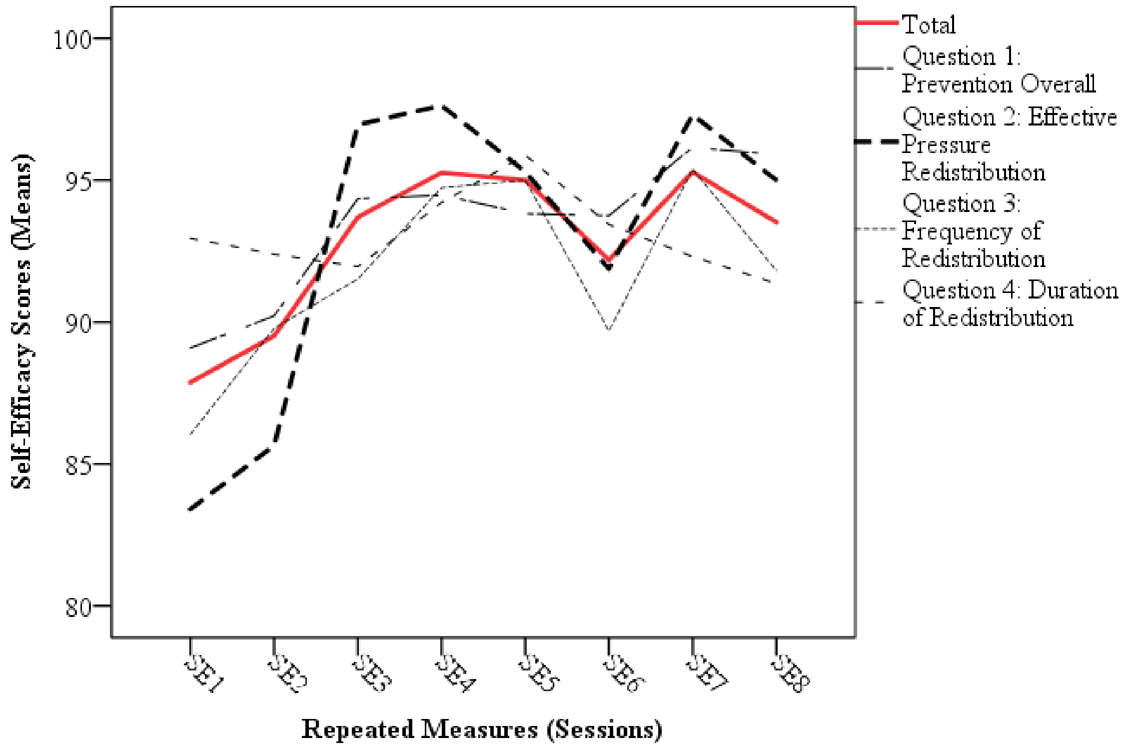

Figure 32. Mean score for each self-efficacy question and total score at each repeated measure. SE1 Baseline; SE2 = Post-Education; SE3 = Education + Map; SE4 = Test-Retest; SE5 & SE7 = Phases With Map; SE6 & SE8 = Phases Without Map.

Inferential statistical analyses of self-efficacy data. To control for individual differences in baseline self-efficacy and individualized changes in scores following interventions, linear mixed-effects regression modeling was used to evaluate the two hypotheses concerning self-efficacy. The models for each of the two self-efficacy measures are shown in Table 16. Visual inspection of residual plots did not reveal any apparent deviations from homoscedasticity of normality. Kenward-Roger approximation of degrees of freedom was used to evaluate the significance of differences in fixed effects.

Table 16.
Self-efficacy Mixed Effect Models

	Self-Efficacy	Self-Efficacy
	Initial Visit	Field-based
	Fixed effects	
Intercept: Baseline β (SE)	84.05 (4.12)	
After Standard Education β (SE)	5.46 (2.90)	
With Map as Feedback β (SE)	**9.64 (4.52)***	
Intercept: Map Used β (SE)		93.9 (1.85)
Map Not Used β (SE)		**-3.21 (.94)****
	Random effects	
Participant		
Variance (SD)	761.99 (27.60)	94.64 (9.73)
Time		
Variance (SD)	92.26 (9.61)	3.90 (1.97)
Residual		
Variance (SD)	50.68 (7.12)	21.96 (4.69)
ICC_{ID}	0.94	0.808

Note. *p < .05. **p <.01.

Model 1 included the total self-efficacy score (Table 16, Model 1) as the dependent variable, with each repeated measure as a factor-based fixed effect. The factors in this effect include the following three repeated tests: baseline (SE1), post-education (SE2), and education plus map feedback (SE3). A random intercept (random effect) for each participant accounted for variability between them and time as an additional random effect since these are repeated measures given sequentially during the initial session. Time was set up as a continuous variable to reflect that the three administrations were repeated measures of the same instrument.

After controlling for participant variation and repeated measures, the baseline estimate for total self-efficacy score was 84.05 (SE=4.12). Total score did not significantly increase following standard education for performing weight shifts (β= 5.46, SE=2.9, t= 1.88, ICC= .94, p= .07). Total score was, however, significantly improved from baseline following introduction of pressure map as visual feedback to guide weight shifts (β= 9.64, SE=4.52, t= 2.13, ICC= .94, p= .04) (Table 16, Model 1) (Figure 33). To compare self-efficacy score post-education with post-education plus map use, pair-wise comparison of model coefficients via least-square means with 95% confidence level and Kenward-Roger degrees of freedom approximation was calculated (Table 17). When comparing post-education with post-education plus pressure mapping, the total score improved an additional 4.18 points (df=42.1, t-value=1.44, p=.16). While the overall self-efficacy score was significantly improved from baseline with addition of the pressure mapping system, there was not a statistically significant increase between education and addition of the pressure map feedback.

Table 17.

Estimate is the Amount in Points (0-100) by which the Total Self-efficacy Score Increased Between the Two Repeated Measures

	Estimate	Std. Error	df	t value	lower	upper	Pr(>|t|)
SE1 vs SE2	-5.46	2.90	42.10	-1.88	-11.31	0.40	0.07
SE1 vs SE3	-9.64	4.52	22.00	-2.13	-19.02	-0.26	0.04*
SE2 vs SE3	-4.18	2.90	42.10	-1.44	-10.04	1.67	0.16

Note. Std. = standard; df=degrees of freedom; SE1=baseline measure; SE2=after education; SE3=after education plus map use.
*p <.05

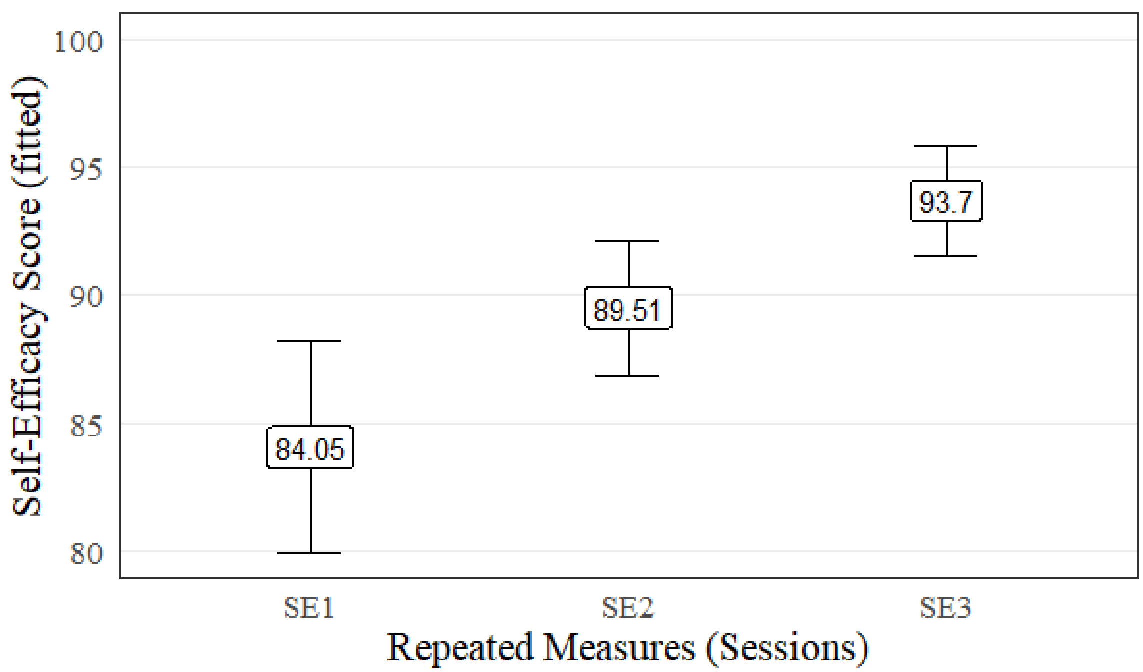

Figure 33. Fitted estimates for self-efficacy score following each intervention: Education (standard) and Education + Pressure Map as feedback. SE1 = Baseline; SE2 = Post-Education; SE3 = Education + Map.

To evaluate the second self-efficacy related hypothesis, the model was similar to Model 1 except time was removed from random effects the comparison was between all session when the participant had access to the pressure mapping system versus the sessions when they were instructed to not use the system for feedback.

To compare total self-efficacy scores between periods when the pressure map was used with when it was not used throughout the study, total scores were grouped: with map vs. without map and did not include baseline (SE1) or retest (SE4) scores. After controlling for participant variation, with the map, the estimated group mean total self-efficacy score was 93.9 (SE=1.85) (Table 16, Model 2). Total scores were statistically significantly lower for the "without map" group (β= -3.21, SE=0.94, t= -3.421, ICC= .81, p= .0011) (Table 16, Model 2) (Figure 34).

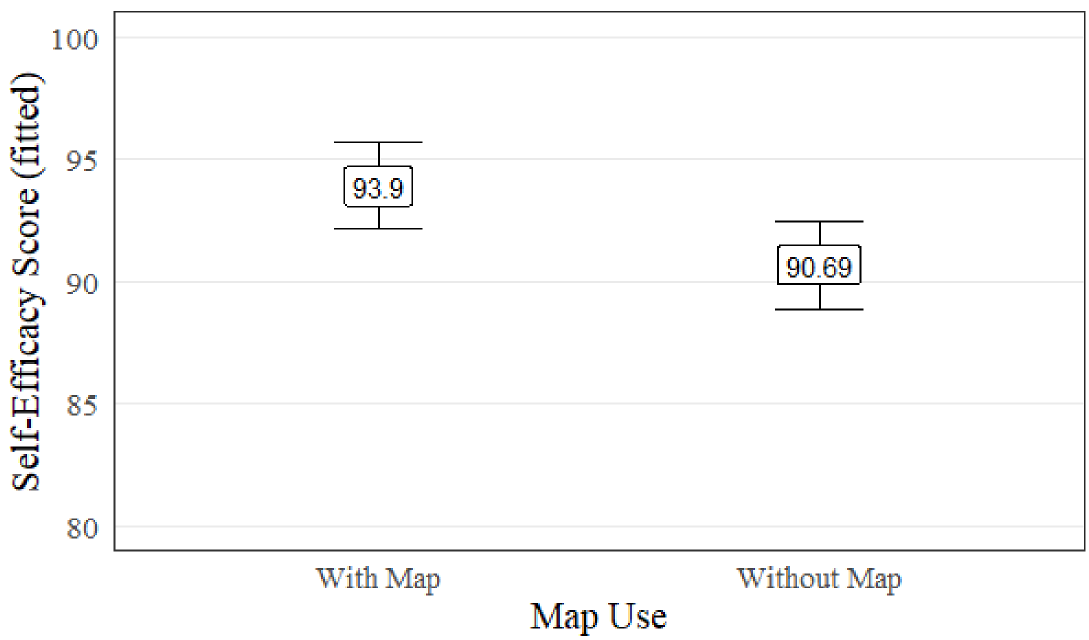

Figure 34. Comparison of fitted estimates of self-efficacy between interventions using map and those not using map.

In summary, the findings for the self-efficacy dependent variable and hypothesis tests' results reached level of significance for an increase in self-efficacy following use of a pressure map to guide weight shifts when compared with baseline, but not when compared directly with education for completing weight shifts (Hypothesis 3). Self-efficacy improved after education, and then improved more after use of the pressure mapping system. The cumulative impact produced a significant increase in self-efficacy, but not use of the pressure map alone. Self-efficacy during field-based use of the pressure map system (Hypothesis 4) was statistically significantly higher with the pressure map than without it. Thus, we can infer that self-efficacy for performing weight shift maneuvers increases with use of pressure mapping as biofeedback to guide the performance of weight shifts.

Discussion

Trunk Activity

We predicted that in a population of individuals with a complete spinal cord injury (SCI) who are wheelchair users, overall trunk activity would increase with access to visual feedback about how pressure was distributed. Trunk activity increased from 44% to 47% when a pressure map was used by wheelchair users with SCI, in alternating weeklong phases, over a period of one month, after accounting for individual variations in movement. This increase translates to an average additional 25 minutes of trunk activity per day when visual feedback from pressure mapping is used. These findings confirm that use of visual feedback had a positive impact on overall trunk activity in wheelchair users with complete SCI.

In individuals with normal sensory function, human factors studies have described the strong linear relationship between feeling discomfort and frequency of movement. A study on seated workers reported that both discomfort and movement increased together over time, (Bhatnager, 1985). Another human factors study on in-chair movements in seated telephone operators found both an increase in movement over a 2-hour period and a linear relationship between movement and reduction in pressure distribution (Fenety, 2000). Reenalda et al. (2009) found that people without sensory or motor impairment tend to move 7.8 ± 5.2 times per hour, or about once every 8 minutes. Unfortunately, individuals with SCI tend to have long periods of inactivity, typically >1 hour, without movement, as well as sporadic patterns (within and between subjects) of movement, as described in several studies reporting movement patterns in wheelchair users (Ding et al., 2008; Sonenblum & Sprigle, 2011a; Sonenblum, Sprigle, & Martin, 2016; Yang et al., 2009).

Comparing the finding of 25 more minutes per day, or 4% more trunk activity, with pressure map use with the results from other published work is a challenge because they either defined, reported, or measured in-chair trunk activity differently. Regarding use of pressure mapping as visual feedback, the studies use pressure sensors in various configurations to monitor movement, but none provide visual feedback showing seat interface pressure to the wheelchair user (Tung, Stead, Mann, Pham, & Popovic, 2015; Verbunt & Bartneck, 2010; Yang, Chou, Hsu, & Chang, 2010). Previous research focused on measuring specific weight shift counts, and they measure weight shifts using under cushion pressure sensors or sensors attached to the tilt mechanism of power tilt systems. Also, they reported the frequency of movements occurring rather than the percentage of the day being active.

Another overall activity measure in this population is physical activity or wheelchair propulsion and not specifically trunk activity (Ding, Hiremath, chung, & Cooper, 2017). Physical activity-focused results obtained by Bucholz, McGillivray, and Pencharz (2003) are consistent with the premise that reduced sensation results in reduced movement. They found that individuals with a complete SCI moved 25% less in a typical day than those with incomplete SCI through measures of total daily expenditure. Because they measured activity in terms of heart rate and energy expenditure, we are not able to compare findings of how much individuals with SCI move their trunks each day.

Despite the lack of studies that specifically focus on measurement of trunk activity in wheelchair users, there are some similarities between the existing mentioned studies and this study. The average time observed as in-chair in this study was 13.6 hours (M=13.6, SD=2.6). Each participant also completed a daily log, including time in the chair each day. The participants estimated their time in the chair as about 1 hour/day lower than that detected from the accelerometer data (M=12.5, SD=2.3). In other studies, time in chair per day for this population ranged from 9.2 to 11.8 (Sonenblum & Sprigle, 2016a; Sonenblum & Sprigle, 2018; Yang et al., 2009). These studies reported a lower average time in the chair each day but they all excluded time between transfers in/out of the chair. In our research study, the time includes all time from initial time in the chair to time out of the chair at night and thus, likely included transfers to other surfaces in between such as a car or commode. Other studies have commented on the variation in movement and patterns of movement between participants, similar to the results in this study.

Covariates (age, level of injury, type of wheelchair, prior history of pressure injury, onset time since injury) were explored when attempting to determine any patterns in who moved more or less than the others or who may have responded differently to use of visual feedback from the pressure map. Participants with thoracic injuries, under 40 years old experienced an increase in movement with pressure map use, while those with cervical level injuries, over 40 years old had the opposite result. They tended to have less movement with map use. The latter group also used tilt to perform weight shifts. When reviewing the comments from participants who were either over 40 years old or had a cervical level injury, the three that met both criteria and had made comments: 1. "I could see that I was relieving pressure when I leaned and looked at the map. I was more aware of pressure when using the map. I saw a lot of red along one side and couldn't make it better with repositioning. As a result, I made an appointment with seating clinic." 2. "I'm more conscious of pressure when using the mapping system. I use tilt more when using the mat because I'm way more conscious of pressure." 3. “You can see the pressure, so you're moving more. It reminded me to move." (Appendix E)

One manual wheelchair user, in particular, experienced a dramatic increase in trunk activity when the pressure map was used. Participant ID #08 experienced a 23.8% increase in trunk activity. However, these results need to be interpreted with caution because this participant missed a considerable number of data collection days due to equipment issues. This participant had only eight total days of data collection, five while using the map and three without the map. This participant’s comments indicate that perhaps the visual feedback was helpful and that this increase in movement was actually due to the presence of the pressure map: “I could see differences on the map if I changed something.” That participant also sent the following in an email shortly after the study concluded indicating that while using the pressure map at home, a problem was detected in the way the seat and backrest were set up on his chair causing higher pressure readings under one side of his bottom. He was able to detect the problem independently and make an appointment with a seating specialist for adjustments. He stated, “The only reason I was able to investigate as I did and know what needed to be done and what appointment to make was because of the map. Saved me a lot of time, money for different appointments, etc. Just thought I'd let you know. I thought it was super cool before, but now it has already proved how useful it is to have." The increase in activity for this person during the time of using the map could be attributed to his increased movement in trying to problem solve the source of increased pressure detected by the map.

Participant, ID #14, who has a history of prior pressure injury, had the least amount of active trunk movement of all the participants with and without map use. A power w/c user with a cervical level injury, this participant also demonstrated one of the more dramatic increases in activity when using the map than without, 8.4% or about 55 min/day increase in trunk activity. This participant’s comments corroborate the increased activity. “The map helped me tilt more often. I was more aware. Was cool to watch pressure change on the map on the phone. Helpful when I go out to know I can tilt in small distances to relieve pressure and felt more able to do that when out in public, like at a restaurant.”

Comments from the three participants who did not have increased trunk activity with pressure map use were still positive about the usefulness of the map: "You can see the pressure, so you're moving more. It reminded me to move", "Found the map helpful. When I saw red, I got wigglier in my chair, and the pressure looked better. I really liked that part of it", and "I was more conscious of pressure when using the mapping system. I used tilt more when using the mat because I'm way more conscious of pressure" (Table 13). These comments could also reflect a disconnect between the participant wanting to please the researcher or appear positive about the pressure map device and their actual movement.

Because the study days were divided between four phases, the pattern of trunk activity was also explored as it related to each phase. Trunk activity was lower during the second mapping phase (A2) than during the first mapping phase (A1) (Table 12). It is difficult to conclude this finding, though, because not all of the participants' study days followed this sequence and a few of the participants did not have study days in the second mapping phase (A2). Five of the 16 participants had B1 as their first phase, followed by A1. One consistent pattern, though, is that A1 always preceded A2 and same for B1 and B2. So, seeing trunk activity decrease from A1 to A2 could possibly reflect less interest in using the visual feedback. The mobile app did not include reminders or alerts to call attention to the visual feedback or the need to shift weight, so it is possible that user engagement decreased over time.

In summary, regarding trunk activity, how much increase in trunk activity in this population is clinically meaningful? Is it best to measure the effect of the intervention within participants instead of across all participants? We know from other work there is no consensus yet on the ideal dosage (Sonenblum & Sprigle, 2018). Also, it makes intuitive sense that if pressure and reduced movement are leading causes of pressure injury that all increase in movement is beneficial. The answers to the question of how much is clinically meaningful probably dependent on multiple factors and aligns with the widely acknowledged concept that movement is highly individual and requires an individualized approach toward assessment and making recommendations for movement.

Weight Shifts

If trunk activity is a measure of the quantity of movement in a given day (percent of day active), then weight shifts could be considered as a measure of the quality of movement because their purpose is to redistribute pressure in varying degrees. The results were not statistically significant for an increase in partial or full weight shifts with use of pressure mapping. Despite the increase in trunk activity, there does not appear to be a concurrent significant increase in time spent in partial or full weight shift positions as defined and measured in this study.

The methods used in this study to classify weight shifts differ significantly from recent studies where movement activity was monitored in wheelchair users with SCI. In particular, even though a seat interface pressure map was used in this study during training and while at home, all of the data for classifying weight shifts in this study was from a single tri-axial accelerometer on the sternum. The rationale for the use of the accelerometer has been mentioned previously. Classification criteria for detecting tilt angles in this study relied on pre-determined distances for leaning or tilting that were not based on individual pressure distributions even though the actual tilt angles were quite different between participants due to their unique movement patterns or chair setup. In all of the studies that report on the remote monitoring of weight shift behavior in the SCI population, pressure sensors were used (typically 6-8) under the seat cushion to detect the center of pressure changes as the wheelchair user moved. Classification in other studies was usually based on a training session that included the participant performing weight shift sequences while using a seat interface pressure map like the one used in this study. In other studies, the seat interface pressure values were used to determine when a certain threshold of pressure had been relieved or redistributed during the weight shift sequence. The sensors under the cushion were then used to detect the center of pressure changes that correlate to the change in interface pressure (Sonenblum et al., 2016; Yang et al., 2009).

Sonenblum et al. (2016) were the first to monitor in seat movement in manual wheelchair user's everyday routines. They used small pressure sensors (8 total) under the seat cushion to measure the frequency of in-seat movements, weight shifts, and complete offloading. In 28 participants who were manual wheelchair users with SCI, they found high variability within and between participants for all weight shift movements. It is difficult to directly compare the findings from their study to mine since the movement-related outcome was measured in frequency per day while mine was measured in duration of time spent in various positions. Briefly, they defined a full relief of pressure as greater than 90% reduction in pressure. A weight shift was defined as a reduction in pressure of 30-90% for at least 15 seconds. Using these criteria, their participants completed a full weight shift .4±.5 times per hour and a weight shift 2.4±2.2 times per hour. It's not possible to compare the time spent performing weight shifts or the type of weight shifts between the two studies due to the difference in criteria for classification. An advantage to using an accelerometer is that it stays on the person as they transfer or move to other seating surfaces to allow monitoring of tilt and direction angles across several potential scenarios, while the under seat sensor on the wheelchair measures strictly in-seat movements. Placement of the sensors under the cushion may provide a more consistent and reliable measure from day to day because it is not likely to move around but could be impacted by positioning. If they are forward on the cushion or sitting slightly to one side, the center of pressure measurements may not classify movements correctly.

In power wheelchair users, methods differed further. Ding et al. (2008) evaluated the use of power seat functions in power wheelchair users with spinal cord injury not by measuring the movement of the person, but by measuring the movement of the chair. They reported on frequency and duration of use of power seat functions as used in the wheelchair user's daily routines for one week. They, too, found variation in the positions and durations in those positions that individuals preferred to spend their time in, similar to this study. For example, average minutes/day duration spent at tilt angles between 30-40 degrees (similar to partial weight shifts in our study) was 11.6 minutes (M=11.6, SD=21.5) and time spent in greater than 40 degrees (similar to full weight shifts) was

14.8 minutes (M=14.8, SD=28.6). In our study, the power wheelchair users who used power tilt spent about 10% of their day in a fully tilted position (M=.1, SD=.08) and 16.5% of their day in partial tilt (M=.17, SD=.18). These findings are similar to Ding et al.'s for the use of power tilt, even when measured differently.

Similar to the findings for the relationship between covariates and trunk activity, there were specific patterns behind the direction of the results for weight shifts. Individuals with cervical level injuries, older age (over 40) tended to spend more time in partial weight shift activities than those with thoracic injuries who were under 40. They tended to spend more time in full weight shift positions than those with cervical level injuries over 40. Those with a previous pressure injury spent more time in partial and full weight shifts than those without a prior injury. These conditions were true when using the map and when not using the map.

This last observation differs from recent findings in a study by Sonenblum (2018). In that study, in-chair movement was compared between manual wheelchair users with SCI. Those without a prior history of skin breakdown moved more overall. Sonenblum's finding is a contrast to findings in this study, where those with history of previous pressure injury had slightly more trunk activity at baseline (without map use) (M=.50, SD=.2) than those without a history of pressure injury (also at baseline, without map use) (M=.44, SD=.19). Time spent in partial and full weight shift positions were also higher in this study for those with a prior history of pressure injury than those without pressure injury. Conversely, in Sonenblum's study, those with a history of previous injury had lower frequency of weight shifts and pressure reliefs than those without a history of pressure injury for shifting weight. There are likely other demographic factors that explain the differences between findings, for example in Sonenblum's study, all of the participants were manual wheelchair users with thoracic level injuries, and this study included all injury levels and power as well as manual wheelchair users.

When weight shift results were explored at the participant level, in combination with trunk activity changes, there were interesting patterns that highlight unique and positive changes when the pressure map was used. Two of the three participants who presented with decreased trunk activity during map use had an increase in time spent performing weight shifts while using the mapping system. The increase in weight shifts is consistent with their comments. Participant ID #9 had a 7% decrease in overall trunk activity, but an average increase of 54 minutes spent in full weight shift positions. A comment from ID#9: "Found the map helpful. When I saw red, I got wigglier in my chair, and pressure got better." Participant ID #6 had a 3% decrease in overall trunk activity but 21.5 more minutes on average each day performing partial weight shifts while using the map: "I use tilt more when using the mat because I'm way more conscious of pressure."

Only one participant, ID #10, had the opposite of the predicted response when using the pressure mapping system, with decreased trunk activity and reduced time spent in weight shift positions. This participant commented, "You can see the pressure, so you're moving more. It reminded me to move." An explanation for a decrease in overall activity and time spent in all weight shift positions is not apparent. ID#10 was a power tilt user, so it is possible that tilt was used more often, but not far enough to cross the threshold into the partial weight shift zone.

All but participant ID #10, experienced a positive change in movement, whether through trunk activity or through time spent in partial or full weight shifts while using the pressure map. This finding demonstrates that on an individual level, almost all of the participants may have experienced some benefit in movement when using the pressure map.

If following commonly prescribed recommendations for movement, to shift weight every 30 minutes for 1 minute, then during a 13.6 hour day in-chair (the average time found in this study), an individual would need to perform 27 weight shifts for a total time per day in the weight shift positions equating to 27 minutes. Also, these would need to be performed across the entire day with consistent spacing to reduce prolonged periods of sitting in one position. Concerning the proportion of time in a day, 27 minutes in a 13.6 hour day would be .033 or 3.3% of the day. That percentage is based purely on the assumption that the wheelchair user assumes the weight shift position, then returns to the upright position. In reality, while carrying out functional activities, the line between sitting upright in a "normal" position and completing a weight shift is likely quite blurry. In this study, the combined time spent in partial and full weight shifts was approximately 22% of the day. Perhaps the method of measuring and accounting for time spent in weight shift positions was inaccurately classifying positions. Previous studies have counted the frequency of shifts but not total time spent in offloading positions. Perhaps a combination of counting weight shifts and also tracking time spent in offloading positions would help us provide individualized and detailed feedback to wheelchair users about their movement patterns.

In summary on weight shift findings, the question remains about how much change in time spent in weight shift positions is considered clinically significant. This likely also depends on many factors, similar to trunk activity, and based on individual needs for pressure relief. Additionally, the results for weight shift positions are reliant on the method used to measure them. A combination of trunk tilt angle with a sensor attached to the person and center of pressure change measured under the seat cushion may be more robust than each one on its own and should be considered in future work to measure daily movement behaviors in this population.

Education with Pressure Map: Impact on Self-efficacy

This study used four carefully constructed questions targeting self-efficacy for performing weight shifts to measure whether self-efficacy improved with education by standard clinical guidelines and with the addition of visual feedback from seat interface pressure mapping. Test-retest correlation of the self-efficacy scale was strong. The total score increased after education was provided and increased by nearly the same amount again after the pressure map was used to guide weight shifts.

In this study, question two had the most substantial increase between baseline, education, and pressure map use out of all four items. Of the four self-efficacy items used in this study, question two, in particular, targeted the use visual feedback and beliefs about effectiveness in relieving pressure by moving far enough. Seeing the pressure change, especially watching the high pressure under the bony areas shift to other areas or change color from red to green or blue on the computer or phone screen in real time, while moving, was especially helpful to the participants, based on their comments.

Other studies have examined the use of the pressure map to increase self-efficacy in caregivers in a hospital or care setting for turning patients at risk for pressure ulcers. While they did not use a self-efficacy scale to measure that specifically, at least one measured nurses’ responses to questions related to mastery of repositioning their patients (Siddiqui, Behrendt, Lafluer, & Craft, 2013). In that study, over 90% of the nurses indicated they believed pressure mapping was helpful for detecting pressure and showing when relief occurred, similar to question one on the self-efficacy scale used in this study which asked about the belief that performing weight shifts helps prevent pressure injury. Eight-eight percent thought it helped with following the hospital's protocols, similar to individuals in wheelchairs following the prescribed or recommended weight shift routine. Also, 84% reported that the use of the pressure map helped them be more effective and efficient in performing repositioning tasks. This last statement is most related to question two on the self-efficacy scale used in this study which asked about whether the participant believed they could move far enough to redistribute pressure effectively.

Self-efficacy assessment scales developed specifically for the spinal cord injured population exist, but none specifically ask about beliefs about moving far enough to be effective in redistributing pressure. Hug et al. (2018) used a different approach with self-efficacy scales and pressure ulcer prevention behaviors in their study. They used a survey to compare general self-efficacy using the General Self-efficacy Scale (GSES) (Jerusalem & Schwarzer, 1992) with five questions about prevention behaviors. The five questions about prevention behaviors were formatted to ask about self-efficacy in performing the tasks. The tasks included basic prevention strategies: skin checks, bed position, equipment used for managing posture, avoiding sitting when needed, and managing incontinence. None of the questions addressed the performance of weight shift maneuvers in sitting. After surveying 450 individuals in Switzerland with SCI, they found that the GSES was not correlated with the pressure injury prevention questions. This finding makes sense because there are specific behaviors or skills to master to manage one's pressure injury risk effectively.

One scale, The Skin Care Belief Scale (King et al., 2012), asks specific questions about caring for the skin for preventing pressure injuries. The study describes the development of the scale, but the final scale is not published or available to view. A review of the factors evaluated revealed that some touched on weight shifting, but none specifically asked about beliefs around moving far enough to redistribute pressure effectively. A study published recently used the Skin Care Belief Scale in their Korean study to evaluate an 8-week education program for pressure injury prevention offered to their acute spinal cord injured patients after dismissal from rehabilitation (Kim & Cho, 2017). With modification to include a question about the effectiveness of weight shift method, the Skin Care Belief Scale may be an excellent option to use in a future study.

Additional self-efficacy scales for the SCI population include one for exercise-related efficacy (Kroll, Kehn, Ho, & Groah, 2007) and one that focuses on self-efficacy for manual wheelchair mobility related factors (Fliess-Douer, van der Woude, & Vanlandewijck, 2011). The Moorong self-efficacy scale, initially developed in 2003

(Middleton, Tate, & Geraghty, 2003), was validated for use with Americans with SCI in 2009 (Miller, 2009). The questions in the Moorong scale focus on broad topics of well-being and quality of life and not on specific self-care or preventative behaviors or tasks. Self-efficacy is context specific; thus even if these well-developed scales for the SCI population were used to measure self-efficacy, and indicated high self-efficacy, they may entirely miss the factors for performing weight shifts that are critical to developing a sense of mastery. Thus, the clinician or researcher using one of these scales, if they are interested in pressure ulcer prevention, in particular, may miss a critical piece of the puzzle.

There is support for the use of visual pressure mapping feedback to provide simple and effective input during education as a strategy for improving self-efficacy. The results in this study were significant for improved self-efficacy for performing weight shifts after delivering standard education and use of pressure mapping. Use of a pressure map while providing education to individuals with a spinal cord injury, and possibly to their caregivers, appears to have a positive impact on self-efficacy and should be encouraged in clinical settings.

Pressure Map Use in Daily Routine: Impact on Self-efficacy

The final hypothesis predicted that self-efficacy scores would be higher overall when the participant was using the pressure map versus when they were not using it. Results of this study confirm that this is true. The comments from participants in this study indicated that the pressure map feedback was helpful day to day to manage pressure but also to detect problems early so that they could take action to resolve them.

First, use of the pressure map in one's daily routine had a positive impact on trunk activity as discussed earlier. An analysis of any correlation between self-efficacy measured in this study with trunk movement changes was not within the scope of the project but would be interesting to evaluate in a future study. For now, we can assume there might be a correlation based on both factors increasing with map use. The social cognitive theory explains that early efficacy expectations are learned from performing tasks and achieving mastery in those tasks. Thus, if a wheelchair user can repeatedly verify that they have moved far enough to get high pressure away from bony areas, they develop a sense of personal achievement that leads to additional behaviors toward the outcome expectation that they will prevent pressure injury.

Additionally, early detection of problems that could result in a pressure injury, by viewing them on the mobile pressure map, contributes to an increase in efficacy expectations for managing weight shifts. Two of the participants identified issues with their seating systems and made appointments with their seating specialist to get it assessed further. The ability to detect problems early is empowering and provides the wheelchair user with a sense of control, a sense of personal achievement and, ideally, leads to improved self-efficacy. Both participants indicated they would not have known to reach out for assistance had they not detected high pressure while going about their daily routines by using the pressure map. By self-identifying the potential problem and taking action, they are increasing their belief in their ability to manage their skin health. Future self-efficacy scale development for weight shift performance should include a factor related to early identification of problems as this was not included in the four questions asked in this study.

Self-efficacy while using the visual feedback can be improved in caregivers as well. There aren't studies that explicitly seek to understand self-efficacy for pressure redistribution effectiveness in wheelchair users, but Gunningberg and Carli’s 2016 study examined the effect of pressure map feedback on repositioning efforts by nurses in a care setting. They found a reduction in peak pressures in the patients whose nurses were guided by the visual feedback and the nurses reported unanimously that the pressure map was easy for them to interpret. An interesting finding is that the nurses who could see the pressure distribution used more strategies to position their patients than without the pressure map feedback. Thus, while using the visual feedback, a change occurred, similar to the findings for trunk movement and also for self-efficacy in this study. These studies support the use of visual feedback to improve one's sense of mastery over the task of managing pressure through movement.

Study Limitations

Limitations of this study include unanticipated problems with the mobile pressure mapping web application technology and support for that technology, challenges in recruitment and retention, and methods used for collecting and interpreting data from the accelerometer.

The web application used in this study was a prototype tool and thus, had limited functionality and limited technical support. We do not know with 100% certainty whether the participants used the pressure mapping system only during the assigned days because we did not have access to the server logs to view frequency of logging into the study. Even with complete daily log stating they used the pressure map or didn't use it on the assigned days, we do not have a way to validate that. Future work can remediate this limitation through the use of an advanced version of the mobile pressure mapping application which provides this information.

Along with functionality limited to viewing and recording pressure, there were shortcomings identified by participants for other parts of the system. Some manual wheelchair users indicated that the pressure map was a challenge to keep in place during transfers and the USB cords of one of the maps was severed. A few participants also commented that the parts and cables were sometimes hard to manage. Participants provided suggestions to incorporate the pressure map into a cushion cover. The mobile pressure mapping system is not yet commercial-ready, and it is not yet known what the cost to end-users may be, but we can anticipate that there will be a requirement for smartphone and data plan and potentially a subscription fee for the pressure map service. These costs may be prohibitive to many wheelchair users. Also, on a daily basis, there are some burdens to the user to use the device. Currently, the system needs to be charged daily, and there are two separate boxes and two cords in addition to the mat and the phone that need to be managed. Changes to the hardware need to include packaging to reduce the total number of parts and connections required.

Recruitment and retention was a challenge in this study. Of the 23 participants who completed the first research visit, only 16 had complete data at the conclusion of the study. We were unable to extend the timeline to allow recruitment of additional participants because the information technology team decided to discontinue support for the mobile web application used in the study. The response from potential participants indicating interest in study participant was high, but several potential participants were unable to enroll because they had current skin problems.

A third limitation of this study involves the methods of collecting and analyzing trunk activity using a single tri-axial accelerometer. Several methodological limitations can be improved for future studies. First, when we measured trunk activity for each participant, it was after delivery of education and use of the map to guide their movements during the initial research visit. An alternative approach may have been to measure true baseline trunk activity in their home before education or use of visual feedback. This way, we could measure better the impact of education with the map on trunk movements. It is possible that the education process and use of the pressure map during the initial research visit had an impact on trunk movement that may have minimized the overall difference in trunk activity between phases. The effect size of changes in movement may be higher if comparisons are made with true baseline measures.

The lack of control over the exact placement of the accelerometer on the participants in the field makes it possible that the weight shift data has inaccuracies due to sensor movement, shifting, or incorrect positioning. Additionally, the weight shift classifier was determined from movements completed during the research visit that the participant may not perform in their daily routines to relieve pressure. For example, during the education training, comments were made by participants that indicate they learned they did not need to move very far to redistribute pressure significantly. During the visit, each participant was asked to perform the same partial and full movements, regardless of whether or not less movement was effective in relieving pressure. When at home, if the participants were then using the visual feedback from the mobile mapping system to guide their weight shifts, they may not have moved as far as they did during the research visit's prescribed movements. Yet, they still may have effectively relieved pressure, which could result in them not moving far enough to cross thresholds set for each type of weight shift.

The pressure map values recorded during the weight shift sequence were not used when determining the thresholds. While this simplified the classification of the data, the thresholds may have been improved had they been based on the amount of pressure relieved instead of how far they traveled. The challenge with that approach, which was used in a recent study (Sonenblum et al., 2016), is that pressure is variable day to day and depends on the placement of the person on the cushion, and many other factors. This factor makes basing a classifier strictly on pressure values a challenge similar to those experience when using a single accelerometer. A combination of tools to measure movement may be more robust to detect weight shifts. Also, because the wheelchair user is sitting on the pressure map when using the mobile pressure mapping app, a simple calculation from the pressure sensors would be center of pressure which could be compared with the accelerometer orientation.

Regarding detection of leans and tilts using an accelerometer alone, if an individual leans forward partially at the hips, but the trunk extends to maintain balance, it is possible that a forward lean occurred without a change in accelerometer orientation. This type of posturing is common in those with thoracic level SCI to maintain their balance by keeping their center of balance just behind the point that would cause them to fall forward. Conversely, if the person flexed their thoracic spine without leaning forward (slumping their shoulders), the orientation of the accelerometer may change and simulate a lean when there was no shift in pressure distribution. This position is likely to occur with fatigue or while resting in their chairs. These factors also support the idea of measuring weight shifts using a combination of center of pressure, as has been done successfully in human factors work and in recent studies about how individuals with SCI in particular move in their chairs, and with an accelerometer for a general measure of activity throughout the day. The accelerometer would detect activity during transfers, while driving, or while performing other tasks out of the chair. For in-chair weight distribution, however, center of pressure and trunk angle together may be a more accurate measure.

Finally, regarding the self-efficacy questions used in this study, while repeatability and face validity were strong, the scope of the questions is limited, and next steps should include the formal development of a self-efficacy scale explicitly aimed at weight shift effectiveness. A comprehensive and similar scale exists, called the Skin Care Belief Scale, which, combined with more targeted questions about weight shifts may provide a more sensitive measurement tool to use in studies that measure the effect of interventions for improving weight shift performance.

Considerations for Future Research on Pressure Map Use in Daily Routine

In future work, the research team should have increased control over when the participants have access to the visual pressure mapping feedback, such as being able to turn off the app remotely when needed to ensure it is not used. The ability to track and analyze usage of the pressure mapping system would be valuable to understand how and when the features are used. The mobile app has been developed further to include these features. The updated version of the mobile app includes alerts based on detection of changes in pressure and reminders based on time. Other features allow users to adjust their settings for the timing of reminders and tracking of their behavior over time. Improvements to the pressure sensing mat are underway in a new study. In that study, the plan is to compare the use of the pressure map mobile app with use of a system that only provides cues for shifting weight (based on under-cushion sensors) through a mobile app. In that study, all movement will be analyzed through the under-seat center of pressure measures, but we may need to consider also using an accelerometer for comparison and/or combination of the two methods to classify weight shifts.

Regarding recruitment, future studies may want to consider allowing enrollment of individuals with existing pressure injuries, especially since this study has shown the positive effect of increased movement with the use of the pressure map. For many with skin injuries, sitting time is limited, and the pressure map could be used during those periods to self-monitor pressure and with increased app functionality described above, could be reminded more frequently of the need to move if a pressure injury is present.

Use of the accelerometer has limitations as described. However, they have many benefits including low expense, long battery life, and data storage capabilities and small size. For future studies, it is recommended that the devices be attached with double stick tape to a marked location on the skin and potentially covered with a small dressing to keep it in place for many days at a time. This more precise and repeatable placement would reduce some unwanted movement of the devices and help make day to day comparisons more reliable.

A classification strategy that combines detection of trunk activity and weight shifts and measures frequency and duration of each with combined use of a single tri-axial accelerometer and detection of the center of pressure changes could provide researchers a feasible and inexpensive method for more accurate and unobtrusive study of movement behaviors and patterns in individuals who use wheelchairs. As described above, the classification strategy should include the use of more movement variation, some based on or determined by pressure values, and should include movements used by the individual in their typical daily routine for improved accuracy in detecting and classifying them.

Obtaining baseline trunk activity and weight shift information in a controlled setting, before use of the map and after use of the map, would provide interesting information on how the movements change with access to the visual feedback. This information could then be used to develop an improved classification system for more accurately detecting weight shifts from data collected over longer periods of time.

Finally, development of a standardized self-efficacy scale for weight shift performance is a high priority. A psychometrically sound self-efficacy measure designed specifically around the performance of weight shifts would be beneficial. First, clinicians could measure the effectiveness of interventions for teaching pressure injury prevention through movement across time and thus, justify the time spent training individuals to use these critical skills. Second, this tool could be used in research to measure outcomes related to pressure injury prevention through movement. With the ability to potentially provide this tool online, it would also be a simple and cost-effective way to gather information from large cohorts of this population and track self-efficacy for managing skin health on a bigger scale and over time as practice changes.

Future research questions to pursue include: learning more about the differences between the level of injury and movement patterns, how the use of alerts or reminders changes movement and self-efficacy for managing pressure, device abandonment or decay of behavior after novelty wanes. Most importantly, we should seek to learn about which wheelchair users find the visual feedback most valuable to their ability to effectively self-manage their skin health.

Conclusion

A small but statistically significant increase in trunk activity occurred with access to mobile, on-demand, seat interface pressure mapping in wheelchair users with spinal cord injury. The results did not confirm with statistical significance that there is a difference related to use of pressure map for time spent in each of the three weight shift zones as they were determined and classified in this study. The results suggest that self-efficacy for performing weight shifts is higher with use of a pressure map for feedback during the education process than with standard education alone, and confirms, with statistical significance, that self-efficacy for performing weight shifts is higher during periods of access to the pressure map as feedback when used in their natural environments and routine.

We learned in this study that access to visual feedback from pressure mapping increases trunk activity and improves self-efficacy for performing weight shifts in wheelchair users with spinal cord injury. More research is needed to understand how individuals with SCI move and the factors that most effectively impact movement. A better understanding of movement patterns can help individualize clinical recommendations and drive the development of more effective interventions. Through the development of a self-efficacy scale with a focus on the effectiveness of movement, researchers and clinicians can better measure the impact of their interventions.

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Appendix A

Daily Log

Participant ID: ______ **Date: ___________**

Time into chair in AM: ______ **Time out of chair in PM: _____**

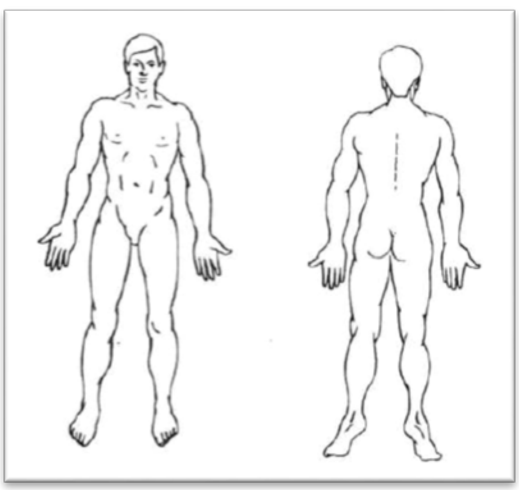
How many times did you get out of your chair during the day? _____

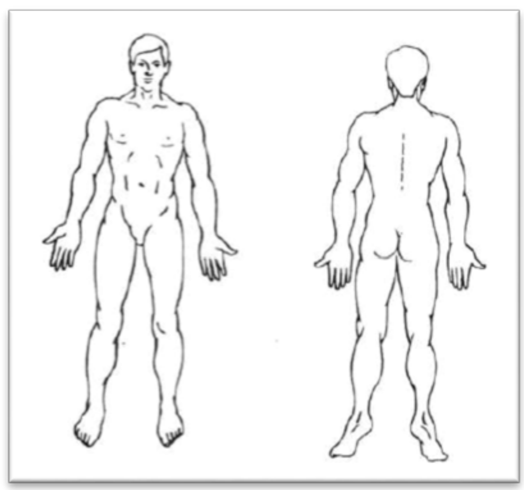
SKIN CHECKS

Check box and indicate time of day skin check was performed.

Place an X on area(s) of concern.

☒ **Time: ________** ☒ **Time: ________**





Describe any skin concerns:

Other comments:

Appendix B

Classification of Trunk Activity

The first step in determining an appropriate classification strategy included observation of accelerometer data in the frequency-based domain for time when the participant's activity was observed and could be validated through pressure map data. In both power and manual wheelchair users, the frequency band during weight shift activities under a controlled environment was very small (less than 1Hz).

Each participant's 10-minute weight shift sequence (WSS) was plotted and carefully observed during the following known events: weight shifts, quiet sitting, flipping of the accelerometer back and forth at start of weight shift sequence, and non-wear time prior to device being placed on participant. For each second of the 10-minute plot, a marker was placed to indicate whether that second counted as active or inactive based on what was known about the participant's activities during that period of time.

This information was then used to train and test a classification method for the same set of data, compare the two for accuracy, and then apply the selected classification strategy across each full data set. It was observed that the general magnitude of acceleration increased along at least one axis by a minimum of .2g during all types of weight shift maneuvers. Classification tested .2g, .23g, and .25g for sensitivity to detecting the same periods of activity as were visually classified earlier.

The most accurate classification of the 10-minute segments occurred when measuring the magnitude change in acceleration values of a minimum of .23g along each axis over a 20-second window, with 50% overlap.

By using 20-second windows, the full movement into or out of a position was counted as active. For example, some tilt actuators move slowly and require up to 20 seconds to achieve the fully tilted position. If measuring a range in acceleration across a shorter window, the classifier does not detect the change in magnitude and misclassifies the time period as inactive. The 20-second window was equally accurate for both manual and power wheelchair users. A 50% overlap further reduced missing periods of change in magnitude of the accelerometer signal along each axis. For example, if during the last 5 seconds of a 20-second window the x-axis increased .15g, and in the first 5 seconds of the next 20-second window, the x-axis value also increased .1g, these periods would each be classified as inactive when all the other axes were under the threshold. With a 50% overlap, however, both of those 5-second windows would occur together and result in a .25g magnitude change in acceleration which is enough to trigger classification as active.

A lower threshold (.2g) tended to overestimate activity while a higher threshold (.25g) tended to miss relevant trunk activity. Overestimation of activity was seen when periods not identified as correlating to a weight shift type movement were classified as active and underestimation occurred when the computer code did not detect the magnitude of change that was visualized as active.

Best accuracy between visual and computer classification training was 94.35% when the threshold was 0.23g. On four sets of test data, overall accuracy was 95.34% with a 0.23g threshold. This classification method applied well to manual and power wheelchair users, and it was not necessary to create different classifiers for each participant.

For each participant, the accelerometer data was processed using the code in the Matlab script shown in Appendix D.

Appendix C

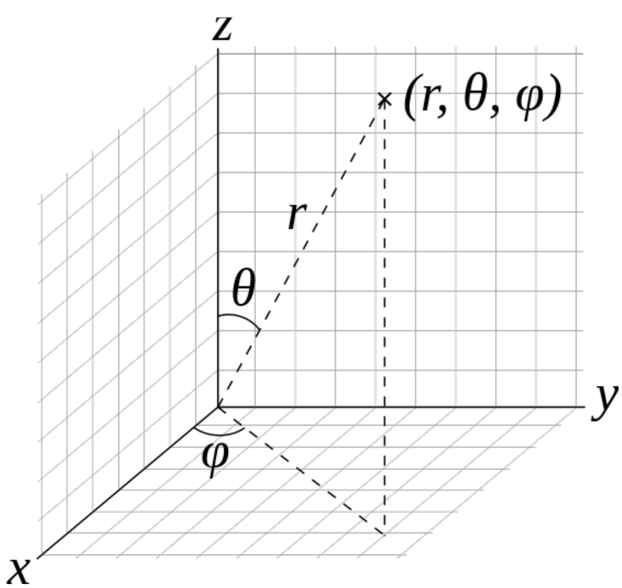
Classification of Weight Shifts

Criteria to determine how much time each participant spent in positions similar to the weight shifts that were performed during the initial visit required the development of a classification strategy. The initial weight shift sequence 10-minute section of the accelerometer signal was used to evaluate patterns for each participant individually due to two factors: the unique way each individual moved during the prescribed weight shifts and their body habitus which could impact orientation of the accelerometer when positioned at the sternum. This section describes the method used to determine individual thresholds for classification of the accelerometer data from field-based part of study into one of three zones of position or weight shift. The zones of movement relate to partial and full weight shift maneuvers as well as the neutral or baseline position. The outcome of this classification was a daily proportion of time spent in each of the three zones.

The steps that were completed include: filter the raw data, calculate tilt and direction angles from the filtered data, determine individually-assigned tilt angle thresholds for each type of weight shift, determine upper and lower limits for each of the three zones of trunk position, classify each sample into one of the three zones using tilt and direction angle criteria, calculate daily time spent in each of the three zones, excluding non-wear time in that calculation.

Filter accelerometer data. The accelerometer data was filtered using a fifth order Butterworth low-pass filter with .25 Hz cutoff frequency. The remaining static portion of the signal was used to calculate tilt and direction angles. After filtering the raw signal, the 10-minute section of known activity was visually observed for each participant, and the weight shifts were detected and validated by observing the playback of the pressure map recordings.

Calculate tilt and direction angles. The calculation to determine the orientation of the accelerometer by tilt angle and direction of tilt was accomplished using a spherical coordinate system. The tilt angle θ in the figure below is the angle used to represent the participant's trunk deviating from an upright position sitting position in their wheelchair. Φ represents the direction of the tilt.



Spherical coordinate system.

To calculate θ, the following equation was used: $Tilt\ Angle\ (\theta\ ) = arccos(abs(z/r))$, where $r = \surd(x^2 + y^2 + z^2)$. To calculate φ, the following equation was used $Direction\ Angle\ (\varphi,) = abs(\arctan(y/x)$. The vector magnitude of the accelerometer signal is r in the equation above. These calculations were done on each sample of the low-pass filtered signal, at 30 samples per second, resulting in new variables for tilt angle and direction angle for each of the samples.

Direction angles determined if the lean was forward or lateral. For those who lean forward and to side for weight shifts, 0-45° defined forward weight shift direction and equal or greater than 45° and less than 135 degrees defined a lateral position. A posterior direction was not defined for the group that performs forward or side leans because the backrest of their chair blocks posterior leans. For participants who used power tilt, the majority of weight shift movement was in the posterior direction, toward 180 degrees and likely between 135 and 180 degrees.

Weight shift thresholds. The next step involved the creation of a threshold for each type of weight shift. For manual wheelchair users and those who leaned to shift weight instead of using power tilt, full forward lean, partial forward lean, full side lean, and partial side lean thresholds here determined by averaging the peak tilt angle for each of the three trials. For power tilt users, thresholds for full and partial power tilt were determined from the average of the peak tilt angle for each of the three trials. The steps below provide more detail about this process.

The 10-minute segment of accelerometer data collected during the weight shift sequence at the research visit was plotted in line with plots of the calculated tilt and direction angles. On the plots, the peak of each tilt angle associated with a weight shift was marked by matching the sample numbers/time for filtered accelerometer and for tilt angle. The mean for each weight shift was used to develop thresholds for three zones that represent the magnitude of tilt.

The tilt thresholds were calculated separately for each type of lean (forward, side, or posterior tilt) because a full forward lean and a full side lean can have very different mean tilt angle magnitudes. For example, some participants were able to lean with larger inclination to the side than forward or vice versa.

Determine upper and lower zone limits. The lower threshold for “Zone 3”, which represents all full weight shifts including forward, side and power tilt, was set at the midpoint between the mean tilt angle for full weight shifts and mean tilt angle for partial weight shifts for the respective types of weight shifts. Any sample with a tilt angle value above that threshold classify the sample as full weight shifts. The upper threshold for “Zone 1”, which represents an upright/neutral position, was set at the point midway between the mean tilt angle for partial weight shifts and 0 degrees. All samples with values below the Zone 1 upper threshold were classified as a Zone 1 sample. All samples between the lower threshold for full weight shifts and the upper threshold for baseline or upright postures were classified as Zone 2, representing partial weight shifts. This process resulted in three bands of position based on tilt angle that each of the tilt angles calculated from the filtered data were compared against in Matlab (Appendix D).

Next, each data sample (tilt angle and direction angle) was evaluated and classified into one of the three zones of movement as described in the dissertation methods chapter, and a daily proportion of time spent in each of the three zones was calculated as follows. The commented Matlab code describes how this was completed.

Appendix D

Matlab Code for classifying trunk activity and weight shifts.

```
%%Vos-Draper Dissertation
%ACTIVITY ANALYSIS
%This script reads in a full accelerometer CSV file for one
participant, up
%to 30 days in length and perform the following tasks:
%       *Classifies active versus not active across full data set
%       *Classifies nonwear time versus wear time full data set
%       *Assigns days of data to mapping versus nonmapping phases
%       *Determines activity type by window for full data set:
Active:mapping,
%           Active:not mapping, Not Active, and Non Wear periods
(30x8640)
%           + PLOT (figure 1)
%       *Determines percent of each hour Active and Not Active
(30x24) +PLOT (figure 2)
%       *Determines daily percent of activity (30x1) + PLOT
(figure3)(WRITE
%           to Data Spreadsheet)
%       *Determines percent of activity by phase (4x1) + PLOT
(figure 4)
%       *Filters raw data with low pass filter to obtain gravity
element
%       *Calculates tilt and direction angles of low-pass
filtered data
%       *Classifies tilt and direction angles into zones based on
magnitude
%           of tilt angle and direction.
%       *Obtain counts for each zone per 10 second period (300
sample
%           counts to get data same length/size as activity
classfied data)
%       *Determine non-wear time for angle data by comparing to
classified
%           activity data.
%       *Determine percent of each hour in each angle zone
%       *Determine daily percent of time spent in each zone per
day (WRITE
%           to Data Spreadsheet)
%       *Determine percent of time spent in each zone per phase

%Deliverable values for analysis: percent of time each day
active, not
%active, or non-wear; percent of time each day in each angle
zone. These
%values will be written to the data collection worksheet in
Excel.

%% LOAD CONSTANTS AND FILE(S) TO PROCESS
clear
```

```
      close all
      clc
      %These values need to be set at start of data analysis and apply
to ALL
      %participants in dataset.
      Th= 0.23; % ENTER THRESHOLD. Stays constant for all participants.
Enter a threshold for magnitude range; values above this will be
considered "active".
      fs=30; %ENTER ACTIGRAPH FREQUENCY (Hz)
      w=20; %ENTER WINDOW LENGTH in seconds for classifying activity
      o=0.5; %ENTER WINDOW OVERLAP: percentage in decimal format
      TotalDays=30; %ENTER NUMBER OF DAYS TO ANALYZE (For R21, used 30
days for all resulting in some of those days not being active but they
get thrown out in stats analysis.

      %% Get participant ID for processing individual participant data
      prompt='Which participant? (format: "PMAP001"):  '; %This string
will be concantenated with parts of filenames later to call files.
      pmapID=input(prompt,'s'); %whatever user types is saved as a
string in pmapID; use later to call files related to this participant.
      AccData=strcat(pmapID,'RAW.csv'); %CSV actigraph raw data files
(1 for each participant, naming convention: "PMAP001RAW.csv"
      %% Get excel worksheet data with mix of numbers and text,
specific to
      %each participant selected, automatically
      [UserDataNums,UserDataTxt,UserDataAll]=xlsread('R21_ACTIVITYINPUT
S_ALL.xlsx',pmapID,'A2:T31'); %Skips row 1 where headers are. Saves all
raw data in UserDataAll, just text in UserDataTxt, and numbers only in
UserDataNums.

      %% Contants below never change or are automatically imported from
files called
      %above.
      studyday=UserDataNums(:,1); %1-30
      WSSstartTime=UserDataNums(1,9); %in seconds from actigraph
initialization; WSS start time during initial visit
      StudystartTime=UserDataNums(1,10); %in seconds from actigraph
initilization; study day 1 start time (could be different from WSS
start time if study day 1 delayed for any reason)
      phase=UserDataNums(:,2); %1='A1' (mapping), 3= 'B1' (not
mapping),2= 'A2' (mapping), 4= 'B2' (not mapping), 'NAN' (neither,
e.g., days that are non-wear would be NAN)
      dayofweek=UserDataTxt(:,2); %names are in all caps for days of
week and fully spelled out
      t1=datetime(UserDataTxt(1,7)); %Creates a date/time (start date)
format that can be called later by each piece (e.g., h1=hour(t1) calls
the hour field)
      actigraphmodel=UserDataNums(1,11); %if it is CLE, need to flip
signs of x and y axes.
      powertilt=UserDataNums(1,14); %determines which part of angle
classifier code to use
      baselineavg=UserDataNums(1,15); %the next 5 lines provide the
average value for each type of tilt obtained from initial WSS.
      fulltiltavg=UserDataNums(1,16);
```

```
        partialtiltavg=UserDataNums(1,17);
        fullsideavg=UserDataNums(1,18);
        partialsideavg=UserDataNums(1,19);
        filesize=UserDataNums(1,20); %if large file, need to process
import differently.
        D=86400; %number of seconds in 24 hour period, use in endTime
when wanting to calculate by number of days
        H=3600; %number of seconds in one hour; use in endTime when
wanting to calculate by number of hours
        M=60; %number of seconds in one minute
        h1=hour(t1); %Time from midnight to startTime in hours
        m1=minute(t1);%Minutes (in rows)remaining from midnight to
startTime
        hrow=10; %Actigraph csv raw data file has 9 rows of header
information at start of each data file.
        startRow=hrow+(StudystartTime*fs);  %Converts seconds to rows
using sample rate (fs) + the header rows. Points to correct starting
row of accelerometer's csv file. (From here, zero padding is added to
front and end of data.)
        WindowsPerHour= H/(w*o); %360 windows per hour (20 second
windows, 50% overlap)
        WindowsPerDay=D/(w*o); %8640 windows per day (20 sec windows, 50%
overlap)
        TotalWindows=TotalDays*WindowsPerDay; %30 days * 8640 windows/day
        TotalHours=TotalDays*24; % 30 days * 24 hours
        TotalRows=(30*D)*fs; %this should be 77760000

        %%Get raw accelerometer data from file automatically
        %two different methods. First is for csv files of <77760000 rows
of data after initial zero padding to previous midnight.
        %the second is for csv files that are larger than 77760000 rows
of data after initial zero padding to previous midnight.
        PadZerosFront=zeros((((h1*H)+(m1*M))*fs),3); %will add
"PadZerosFront" number of zeros to front of acc to fill in to previous
midnight from start time.
        lengthPadZerosFront=length(PadZerosFront);
        PadZeros=TotalDays*D*fs; %Total number of rows in 30 days =
77,760,000 (use to add zeros to end of data set if it does not = this
amount.
        if filesize+PadZerosFront <= 77760000
            accraw=csvread(AccData,startRow,0); %Gets raw accelerometer
file, uses input string to determine name of file to look for. Creates
a matrix with 3 columns and n rows. x-y-z axes.
            %Zero pad front and end of accelerometer data to make all
files the same size
            accraw=[PadZerosFront;accraw]; %concantenate padded acc with
raw acc
            n=length(accraw);
            if n<PadZeros
                PadZerosEnd=zeros((PadZeros-n),3);
                accraw=[accraw; PadZerosEnd];
            end
        else
            EndRow=startRow+TotalRows-lengthPadZerosFront;
```

```
          if EndRow>filesize
              accraw=csvread(AccData,startRow,0);
          else
          accraw=csvread(AccData,startRow,0,[startRow,0,EndRow-1,2]);
          end
          accraw=[PadZerosFront;accraw]; %concantenate padded acc with
raw acc
          n=length(accraw);
          if n<PadZeros
              PadZerosEnd=zeros((PadZeros-n),3);
              accraw=[accraw; PadZerosEnd];
          end
      end

      n=length(accraw); %length of acc after zeros added in front and
back as needed (should always be 77760000)
      %In the .csv file created by Actilife, Axis 1 is y; Axis 2 is x;
Axis
      %3 is z.
      %Accelerometre models from Actigraph have different
orientations:
      %WGT3X+ = up and left are negative. (CLE serial numbers)
      %WGT3X+ BT = up and left. (MOS serial numbers)

      y=accraw(:,1); %these vectors hold each of the three raw data for
each axis, unfiltered. Used to calculate difference between max and min
by window.
      x=accraw(:,2);
      z=accraw(:,3);

      %% Variables related to range (R) within windows for raw data
(essentially
      %cuts size of data down, dividing by number of windows)
      Rn=floor(n/(w*fs*o)); %Rn sets length (in integer) for
matrix/vectors that hold difference values for each axis, and for
Ract/Rx/Ry/Rz.
      RActClass=zeros(Rn,1); % ACTIVITY CLASSIFICATION vector, 259200
long: Did not meet threshold = 0. Meets threshold =1.
      Rx=zeros(Rn,1); %these vectors will hold the calculated
difference between max and min in each window for each axis of
accelerometer.
      Ry=zeros(Rn,1);
      Rz=zeros(Rn,1);

      %% CLASSIFY ACTIVITY
      %Evaluate raw data in each x, y, and z axis, by overlapping
windows to determine if activity occured, determined by meeting a
specified threshold value. Activity = 1 in Ract, Non-active =0.

      j=1; %Counts in increments of 1 for writing classifier data to
RActClass rows and range (difference value) in rows of Rx,Ry,Rz.
      for i=1:(w*fs*o):n-(w*fs)
```

```
        Rx(j)=range(x((i):i+(w*fs)));   %Next 3 lines calculate range
(difference from min to max) of x,y, and z values within specified
window and save it to the specified row in the vector
        Ry(j)=range(y((i):i+(w*fs)));
        Rz(j)=range(z((i):i+(w*fs)));
        if Rx(j)>=Th
            RActClass(j)=1;
        elseif Ry(j)>=Th
            RActClass(j)=1;
        elseif Rz(j)>=Th
            RActClass(j)=1; %if any of x,y, or z meets range
threshold, set value to 1. Otherwise, 0.
        else
            RActClass(j)=0; %Values of 1 or 0 are saved in Ract, a
column array of 259,200 rows.
        end
        j=j+1;
    end
    %Classified data is saved in RActClass (259200 rows)

    %% NONWEAR TIME VERSUS WEAR TIME (based on classifier)
    %This code finds areas of no activity >650 windows (108 min) and
replaces
    %each of them with NaN.
    %RActClass still HAS 2 original CLASSIFICATION LEVELS: 1=Active
0=Not Active.
    %Calculate Non-Wear Time on RActClass
    firstzero=-1;
    zeroctr=0;
    for i=1:Rn
    if (RActClass(i)==0) && firstzero<0
        firstzero=i;
    end
    if firstzero>=1
      zeroctr=zeroctr+1;
    end
    if RActClass(i)==1
        if zeroctr >=650
            for j=firstzero:firstzero+zeroctr
                RActClass(j)=NaN;
            end
        end
        %reset counters
        firstzero = -1;
        zeroctr = 0;
    end
    end

    %RActClass2 is a long vector (259200x1) that HAS 3 activity
CLASSIFICATION LEVELS:  1=Active  0=Not Active   -1=Non-wear
    %This is created for use in heatmap style plots because NaN
doesn't work
    %properly.  I need to assign a -1 to Non-wear for this to display
    %correctly.
```

```
      RActClass2=zeros(Rn,1);
      for i=1:Rn
          if isnan(RActClass(i))
              RActClass2(i)=-1;
          else
              RActClass2(i)=RActClass(i);
          end
      end

      %% CLASSIFIED ACTIVITY PER WINDOW in form that can be put into
heatmap style plot (a table, days:windows (30:8640).
      %Create 30row x 8640col table with activity values -1,0,1 to
indicate activity across columns of time and rows of day.
      ClassifiedActivityperWindow=zeros(30,8640);

      for i=1:30
          ClassifiedActivityperWindow(i,:)=RActClass2((((i-
1)*WindowsPerDay)+1):(i*WindowsPerDay))'; %this just trsnforms
RActClass vector into a table with 30 rows (days) by 8640 (windows)
      end

      %% DETERMINE PROPORTION OF ACTIVITY PER HOUR
      % Creates a matrix 30days x 24hours with the following elements:
      %   *Entire hour is non-wear = (OR NAN)
      %   *Entire hour is not active = 0
      %   *Percentage active per hour = #active windows/(#total
windows+#inactive
      %   windows)

      C1=zeros(720,1); %will store non-wear windows per hour in each
row
      C2=zeros(720,1); %will store inactive (but wearing) windows per
hour in each row
      C3=zeros(720,1); %will store active windows per hour in each row
      RClassActivityByHour=zeros(720,1);  %column vector to hold
calculated hour-long activity (-1=nonwear; 0=inactive; other value
between 0-1 is percent active if there is activity.
      k=1; %counts rows for saving sums of hourly activity to kth row
in C1, C2, C3
          for i=1:360:Rn % i counts from 1 to total windows (259200) by
360 (hourly)
              C1(k)=sum((isnan(RActClass(i:i+360-1))));  %Sum of non-
wear windows. If all 360 values are NaN, then this is non-wear for full
hour; Value saved in k'th row of C1.
              C2(k)=sum((RActClass(i:i+360-1))==0);  %Sum of non-active
windows. If all 360 values are 0, then this this is one full hour of
inactivity (but presumed wearing actigraph)
              C3(k)=sum((RActClass(i:i+360-1))==1);  %Sum of active
windows for full hour
              k=k+1;
          end
          for i=1:720    %loop through each hour, row by row, to
classify the hourly period
```

```
              if C1(i)>=360
                  RClassActivityByHour(i)=NaN;  %Nonwear period (NaN)
                  else
                  RClassActivityByHour(i)=C3(i)/(C3(i)+C2(i)); %Percent
Active for hour
              end
          end

      %Create 30x24 table with activity values -1,0,or percentage of
activity to indicate activity across columns of time and rows of day.
      ClassifiedActivityperHour=zeros(30,24);
      for i=1:30
          ClassifiedActivityperHour(i,:)=RClassActivityByHour((((i-
1)*24)+1):(i*24))';
      end


      %% DETERMINE PROPORTION OF ACTIVE TIME PER DAY

      C1d=zeros(30,1);
      C2d=zeros(30,1);
      C3d=zeros(30,1);

      ClassifiedActivityperDay=zeros(30,1);  %column vector to hold
classifiers by day

      %will be a percentage of time. There should be 30 rows at the
end.
      for i=1:30
          C1d(i)= sum((C1((i-1)*24+1:i*24))); %Calculates non-wear
time; unlikely for entire days but could show up for those who don't
wear it for a day.
          C2d(i)= sum((C2((i-1)*24+1:i*24))); %Calculates number of
windows that are inactive for day
          C3d(i)= sum((C3((i-1)*24+1:i*24))); %Calculates number of
windows with activity
      end
      for i=1:30    %loop through each day, row by row, to calculate
percentage of time active and save it to a row in ActiveByDayTable
              if (C1d(i)>=7200) %an entire day of nonwear if at least
7200 windows are non-wear. This occurs if for the entire day, there are
less than 4 hours of windows total with activity. This means that only
dyas with at least 4 hours of actigraph time are counted.
                  ClassifiedActivityperDay(i)=NaN;
              else

ClassifiedActivityperDay(i)=(C3d(i)/(C3d(i)+C2d(i))); %Calculate
percent activity for day (active divided by (active + inactive).  This
omits NaN values from calculation.
              end
      end

      % %%WRITE PERCENT ACTIVE PER DAY TO EXCEL SPREADSHEET
```

```
    %xlswrite('R21_ACTIVITYINPUTS_ALL.xlsx',ClassifiedActivityperDay,
pmapID,'L2:L31');


    %% DETERMINE PROPORTION OF ACTIVE TIME PER PHASE

    %Phase category stored in: phase=UserDataNum(:,3); (30 rows)
(Values are strings.
    A1=zeros;
    A2=zeros;
    B1=zeros;
    B2=zeros;
    for i=1:30
        if phase(i)==1
            A1(i)=ClassifiedActivityperDay(i);
        elseif phase(i)==3
            B1(i)=ClassifiedActivityperDay(i);
        elseif phase(i)==2
            A2(i)=ClassifiedActivityperDay(i);
        elseif phase(i)==4
            B2(i)=ClassifiedActivityperDay(i);
        end
    end

    %%DETERMINE PROPORTION OF ACTIVITY PER PHASE TYPE(CONDITIONS =
MAPPING OVERALL VERSUS NON-MAPPING OVERALL.

    CombinedAPhases=[A1 A2];
    CombinedBPhases=[B1 B2];
    APhases=nanmean(CombinedAPhases);
    BPhases=nanmean(CombinedBPhases);
    CombinedPhases=[APhases,BPhases];

    %%  ANGLE CLASSIFICATION

    % Low Pass Filter, 0.25Hz cut off; obtain gravity portion of
signal and save
    %it to filtacc. Then create individual vectors for each filtered
axis.
    %Calculate vector magnitude value and save to
    %filtvm.

    filtFq=0.25;
    filtOrder=5;
    filtType='low';
    [b,a]=butter(filtOrder,filtFq/(fs/2),filtType);
    filtACC=filtfilt(b,a,accraw);
    filtY=filtACC(:,1);
    filtX=filtACC(:,2);
    filtZ=filtACC(:,3);

    if actigraphmodel==2 %if Actigraph model starts with "CLE", y=-1
is upright and x=-1 is upright with device tipped 90 degrees to right.
        filtY=-(filtY);
```

```
        filtX=-(filtX);
    end

    % Equations for angle calculation
    filtVM= sqrt(filtY.^2 + filtX.^2 + filtZ.^2);
    TiltAngle= acosd(abs(filtY)./filtVM);
    TiltAngle=abs(TiltAngle);  %this converts from complex double
type to double.
    DirectionAngle= abs(atan2d(filtX,filtZ)); %absolute value used
because I'm not differentiating between right/left side leans. For
"leaners" there aren't any posterior leans and for "tilters" I'm
measuring tilts.

    %ALTERNATIVE AXES ARRANGEMENT FOR PMAP008, PMAP024
    % TiltAngle= acosd(abs(filtZ)./(filtVM));
    % TiltAngle=abs(TiltAngle);
    % DirectionAngle= abs(atan2d(filtZ,filtX));

    %Use Imported Mean angles for full, partial, and baseline (tilt
and side leans)
    %from Excel spreadsheet to caluculate lower and upper limits for
"Zones".

    FtiltTh=(fulltiltavg+partialtiltavg)/2;
    PtiltTh=(partialtiltavg+baselineavg)/2;
    FsideTh=(fullsideavg+partialsideavg)/2;
    PsideTh=(partialsideavg+baselineavg)/2;

    %Forward Leans
    FFLean=zeros(n,1);
    PFLean=zeros(n,1);

    %Side Leans
    FSide=zeros(n,1);
    PSide=zeros(n,1);

    %Posterior Tilt
    Fbacktilt=zeros(n,1);
    Pbacktilt=zeros(n,1);

    Notilt=zeros(n,1);

    FbacktiltEpoch=zeros(Rn,1);
    PbacktiltEpoch=zeros(Rn,1);
    FFLeanEpoch=zeros(Rn,1);
    PFLeanEpoch=zeros(Rn,1);
    FSideEpoch=zeros(Rn,1);
    PSideEpoch=zeros(Rn,1);
    NotiltEpoch=zeros(Rn,1);

    %Create a new vector for Wear (1 or 0) vs NonWear (NaN)
    NonwearClass=RActClass;
    for i=1:1:Rn
        if isnan(NonwearClass(i))
```

```
            NonwearClass(i)=1; %assigns a 1 for NONWEAR.  NO NaN's in
this array.
         else
             NonwearClass(i)=0; %assigns a 0 if this is NOT a nonwear
period.  Sort of counter-intuitive, but it makes tilt angle zones
calculate correctly.
         end
     end

     EpochCtr = 1;

     %% CLASSIFY LEANS/TILTS USING THRESHOLDS AND DIRECTION ANGLES
     %CREATE BINARY CLASSIFICATION ARRAYS FOR EACH TYPE OF LEAN/TILT
     %CALCULATE 10 SECOND EPOCHS TO HOLD COUNTS FOR EACH LEANT/TILT
ZONE: FFLean, PFLean, FSide, PSide, Fbacktilt, Pbacktilt, and Notilt.
     %Use Rn for length (Rn=floor(n/(w*fs*o)) to create a new array
length that is same size as activity classifier data above (based on
window size).
     %Maximum count per 10 second epoch is 300.

     if powertilt==1
     %Power Tilt
        for i=1:1:n
          if (TiltAngle(i)>FtiltTh)
             Fbacktilt(i)=TiltAngle(i);
             FbacktiltEpoch(EpochCtr)=FbacktiltEpoch(EpochCtr)+1;
             elseif (TiltAngle(i)>PtiltTh)&&(TiltAngle(i)<=FtiltTh)
                 Pbacktilt(i)=TiltAngle(i);
                 PbacktiltEpoch(EpochCtr)=PbacktiltEpoch(EpochCtr)+1;
          else
              Notilt(i)=TiltAngle(i);
              NotiltEpoch(EpochCtr)=NotiltEpoch(EpochCtr)+1;
             end
                if mod(i,300)==0
                EpochCtr = EpochCtr+1;
            end
         end
     else
     %Forward Leans

         for i=1:1:n
             if (TiltAngle(i)>FtiltTh)&&(DirectionAngle(i)<45)
                 FFLean(i)=TiltAngle(i);
                 FFLeanEpoch(EpochCtr)=FFLeanEpoch(EpochCtr)+1;
             elseif
(TiltAngle(i)>=PtiltTh)&&(TiltAngle(i)<=FtiltTh)&&(DirectionAngle(i)<45
)
                 PFLean(i)=TiltAngle(i);
                 PFLeanEpoch(EpochCtr)=PFLeanEpoch(EpochCtr)+1;
     %Side Leans
             elseif
(TiltAngle(i)>FsideTh)&&(DirectionAngle(i)>=45)&&(DirectionAngle(i)<=13
5)
                 FSide(i)=TiltAngle(i);
```

```
                    FSideEpoch(EpochCtr)=FSideEpoch(EpochCtr)+1;
               elseif (TiltAngle(i)>=PsideTh) &&
(TiltAngle(i)<=FsideTh)&&(DirectionAngle(i)>=45)&&(DirectionAngle(i)<=1
35)
                   PSide(i)=TiltAngle(i);
                    PSideEpoch(EpochCtr)=PSideEpoch(EpochCtr)+1;
               else
                   Notilt(i)=TiltAngle(i);
                   NotiltEpoch(EpochCtr)=NotiltEpoch(EpochCtr)+1;
               end
                  if mod(i,300)==0
                  EpochCtr = EpochCtr+1;
              end
           end
       end

       %% SET NON-WEAR TIMES TO NaN IN TILT/LEAN EPOCHS
       for i=1:1:Rn
           if NonwearClass(i)==1
               if powertilt==1
               FbacktiltEpoch(i)=NaN;
               PbacktiltEpoch(i)=NaN;
               NotiltEpoch(i)=NaN;
               else
               FFLeanEpoch(i)=NaN;
               PFLeanEpoch(i)=NaN;
               FSideEpoch(i)=NaN;
               PSideEpoch(i)=NaN;
               NotiltEpoch(i)=NaN;
               end
           end
       end

       %% DETERMINE PROPORTION OF TIME IN TILT/LEAN ZONES PER HOUR

       FF=zeros(720,1);
       PF=zeros(720,1);
       FS=zeros(720,1);
       PS=zeros(720,1);
       FB=zeros(720,1);
       PB=zeros(720,1);
       NT=zeros(720,1);
       NW=zeros(720,1); %Hourly totals: will hold nonwear time sums to
use in calculation of percentages later. Need to multiple these by 300
(10 seconds by 30 Hz rate) to give counts similar to leans/tilts.
       FFClassifiedPerHour=zeros(720,1);  %column vector to hold
percentage of time in each angle zone by day and type of lean/tilt
       PFClassifiedPerHour=zeros(720,1);
       FSClassifiedPerHour=zeros(720,1);
       PSClassifiedPerHour=zeros(720,1);
       FBClassifiedPerHour=zeros(720,1);
       PBClassifiedPerHour=zeros(720,1);
       NTClassifiedPerHour=zeros(720,1);
```

```
	NWClassifiedPerHour=zeros(720,1); %This will hold the 
"rehydrated" nonwear times with number of epochs of non wear per hour 
(original non-wear x 300).

	for i=1:720
	    if powertilt==1
	        FB(i)=nansum(FbacktiltEpoch((i-1)*360+1:i*360));
	        PB(i)=nansum(PbacktiltEpoch((i-1)*360+1:i*360));
	        NT(i)=nansum(NotiltEpoch((i-1)*360+1:i*360));
	        NW(i)=300*(sum(NonwearClass((i-1)*360+1:i*360)));
	    else
	        FF(i)=nansum(FFLeanEpoch((i-1)*360+1:i*360));
	        PF(i)=nansum(PFLeanEpoch((i-1)*360+1:i*360));
	        FS(i)=nansum(FSideEpoch((i-1)*360+1:i*360));
	        PS(i)=nansum(PSideEpoch((i-1)*360+1:i*360));
	        NT(i)=nansum(NotiltEpoch((i-1)*360+1:i*360));
	        NW(i)=300*(sum(NonwearClass((i-1)*360+1:i*360)));
	    end
	end

	for i=1:720 %Loop through each hour, row by row, to calculate 
percent of total hour spent in each tilt/lean zone. Will need to 
subtract non-wear time from denominator to keep it out of calculation.
	    if powertilt==1
	        FBClassifiedPerHour(i)=FB(i)/(108000-NW(i));
	        PBClassifiedPerHour(i)=PB(i)/(108000-NW(i));
	        NTClassifiedPerHour(i)=NT(i)/(108000-NW(i));
	    else
	        FFClassifiedPerHour(i)=FF(i)/(108000-NW(i));
	        PFClassifiedPerHour(i)=PF(i)/(108000-NW(i));
	        FSClassifiedPerHour(i)=FS(i)/(108000-NW(i));
	        PSClassifiedPerHour(i)=PS(i)/(108000-NW(i));
	        NTClassifiedPerHour(i)=NT(i)/(108000-NW(i));
	    end
	end

	%% DETERMINE PROPORTION OF TIME IN TILT/LEAN ZONES PER DAY
	FF2=zeros(30,1);
	PF2=zeros(30,1);
	FS2=zeros(30,1);
	PS2=zeros(30,1);
	FB2=zeros(30,1);
	PB2=zeros(30,1);
	NT2=zeros(30,1);
	NW2=zeros(30,1); %Daily totals: will hold nonwear time sums to 
use in calculation of percentages later.
	FFClassifiedPerDay=zeros(30,1);  %column vector to hold 
percentage of time in each angle zone by day and type of lean/tilt
	PFClassifiedPerDay=zeros(30,1);
	FSClassifiedPerDay=zeros(30,1);
	PSClassifiedPerDay=zeros(30,1);
	FBClassifiedPerDay=zeros(30,1);
	PBClassifiedPerDay=zeros(30,1);
	NTClassifiedPerDay=zeros(30,1);
```

```
        NWClassifiedPerDay=zeros(30,1);

        for i=1:30
            if powertilt==1
                FB2(i)=nansum(FB((i-1)*24+1:i*24));
                PB2(i)=nansum(PB((i-1)*24+1:i*24));
                NT2(i)=nansum(NT((i-1)*24+1:i*24));
                NW2(i)=sum(NW((i-1)*24+1:i*24));
            else
                FF2(i)=nansum(FF((i-1)*24+1:i*24));
                PF2(i)=nansum(PF((i-1)*24+1:i*24));
                FS2(i)=nansum(FS((i-1)*24+1:i*24));
                PS2(i)=nansum(PS((i-1)*24+1:i*24));
                NT2(i)=nansum(NT((i-1)*24+1:i*24));
                NW2(i)=sum(NW((i-1)*24+1:i*24));
            end

        end
        for i=1:30 %Loop through each hour, row by row, to calculate
percent of total hour spent in each tilt/lean zone. Will need to
subtract non-wear time from denominator to keep it out of calculation.
            if powertilt==1
                FBClassifiedPerDay(i)=FB2(i)/(108000*24-NW2(i));
                PBClassifiedPerDay(i)=PB2(i)/(108000*24-NW2(i));
                NTClassifiedPerDay(i)=NT2(i)/(108000*24-NW2(i));
            else
                FFClassifiedPerDay(i)=FF2(i)/(108000*24-NW2(i));
                PFClassifiedPerDay(i)=PF2(i)/(108000*24-NW2(i));
                FSClassifiedPerDay(i)=FS2(i)/(108000*24-NW2(i));
                PSClassifiedPerDay(i)=PS2(i)/(108000*24-NW2(i));
                NTClassifiedPerDay(i)=NT2(i)/(108000*24-NW2(i));
            end
        end

        %%WRITE PERCENT TIME PER DAY IN EACH TILT/LEAN ZONE TO EXCEL
SPREADSHEET
        %
xlswrite('R21_ACTIVITYINPUTS_ALL.xlsx',FFClassifiedPerDay,pmapID,'U2:U3
1');
        %
xlswrite('R21_ACTIVITYINPUTS_ALL.xlsx',PFClassifiedPerDay,pmapID,'V2:V3
1');
        %
xlswrite('R21_ACTIVITYINPUTS_ALL.xlsx',FSClassifiedPerDay,pmapID,'W2:W3
1');
        %
xlswrite('R21_ACTIVITYINPUTS_ALL.xlsx',PSClassifiedPerDay,pmapID,'X2:X3
1');
        %
xlswrite('R21_ACTIVITYINPUTS_ALL.xlsx',FBClassifiedPerDay,pmapID,'Y2:Y3
1');
        %
xlswrite('R21_ACTIVITYINPUTS_ALL.xlsx',PBClassifiedPerDay,pmapID,'Z2:Z3
1');
```

```
      %
xlswrite('R21_ACTIVITYINPUTS_ALL.xlsx',NTClassifiedPerDay,pmapID,'AA2:A
A31');
      % NoTilt=AA2:AA31 PartialBackTilt=Z  FullBackTilt=Y   PartialSide
= X  FullSide=W PartialFront=V  FullFront=U

      %% PLOTS
      %
      % % %raw accelerometer data
      figure(1); %change numbers of figures when code is cleaned so
they are in correct sequence.
      % %Need to make colors more appealing!!  Gross r/g/b colors.
      plot(accraw);
      titlestr=strcat(pmapID,': Raw Accelerometer Data');
      title(titlestr);
      axis tight
      set(gca,'XtickLabel',[]);
      set(gca,'XTick',[]);
      xlabel('Days 1-30');
      ylabel('Acceleration (g)');
      %
      % % %Plot heatmap (imagesc(___)) of activity for entire 30 days

      % figure(2)
      Xaxis=[0 24];
      Yaxis=[1 30];
      im=imagesc(Xaxis, Yaxis, ClassifiedActivityperWindow);
      xlabel('Hours');
      ylabel('Days');
      %titlestr=strcat(pmapID,' Activity Classification by Window');
      %title(titlestr);
      xticks([0 6 12 18 24]);
      yticks([1 5 10 15 20 25 30]);
      set(gca,'XMinorTick','on'); %turns on ticks at each hour along x-
axis
      map=[1 1 1
          0.5 0.5 0.5
          0 0 0];
      colormap(map); %currently plotting with non-wear white (1 1 1),
activity black (0 0 0), Non-active gray (.5 .5 .5)
      colorbar('Ticks',[-1,0,1],'TickLabels',{'Non-Wear Time','Trunk
Inactive','Trunk Activity'});
      % %Plot heatmap (imagesc(___)) of ACTIVITY BY HOUR for entire 30
days
      figure(3)
      Xaxis=[0 24];
      Yaxis=[1 30];
      im=imagesc(Xaxis, Yaxis, ClassifiedActivityperHour);
      xlabel('Hours');
      ylabel('Days');
      titlestr=strcat(pmapID,' Trunk Activity per Hour');
      title(titlestr);
      xticks([0 6 12 18 24]);
      yticks([1 5 10 15 20 25 30]);
```

```
    set(gca,'XMinorTick','on'); %turns on ticks at each hour along x-
axis
    map=[1 1 1
        .95 .95 .95
        .9 .9 .9
        .85 .85 .85
        .8 .8 .8
        .75 .75 .75
        .7 .7 .7
        .65 .65 .65
        .6 .6 .6
        .55 .55 .55
        0.5 0.5 0.5
        .45 .45 .45
        .4 .4 .4
        .35 .35 .35
        .3 .3 .3
        .25 .25 .25
        .2 .2 .2
        .15 .15 .15
        .1 .1 .1
        .05 .05 .05
        0 0 0];
    colormap(map); %darker shades are more active
    colorbar('Ticks',[0,.1,.25, .5, .75, .99],'TickLabels',{'Non-
wear','Inactive','25% Active','50% Active','75% Active','100%
Active'});

    % % %Plot of activity by Phase (2 bars)
    figure(4); %  need to work on labels and color differences.
    bar(1,CombinedPhases(1),'FaceColor', 'g');
    hold on
    bar(2,CombinedPhases(2),'FaceColor', 'r');
    title('Trunk Activity');
    set(gca,'XTick',[1 2]);
    set(gca,'XTickLabel', {'Map' 'No Map'});
    ylabel('Percent of Time');
    ylim([0 1]);

    % %Barchart of activity per day
    figure(5);
    set(gcf,'Color',[1,1,1]);
    bar(A1,'FaceColor','g');
    hold on
    bar(B1,'FaceColor','r');
    bar(A2,'FaceColor','g');
    bar(B2,'FaceColor','r');
    titlestr=strcat(pmapID,' Trunk Activity by Phase');
    title(titlestr);
    xlabel('Day');
    ylabel('Average Percent of Time Active per Hour');
    set(gca,'xtick',[]);
    set(gca,'xticklabel',[]);
    legend('Map','No Map');
```

```
figure(6)
t=(1:1:n-1/30+1)';
if powertilt==1
    plot(t,Fbacktilt,'.r');
    hold on
    plot(t,Pbacktilt,'.c');
    plot(t,Notilt,'.k');
else
    plot(t,FFLean,'.r','DisplayName','Full Forward Lean');
    hold on
    plot(t,PFLean,'.c','DisplayName','Partial Forward Lean');
    plot(t,FSide,'.m','DisplayName','Full Side Lean');
    plot(t,PSide,'.g','DisplayName','Partial Side Lean');
    plot(t,Notilt,'.k');
end
titlestr=strcat(pmapID,':Classified Tilt Angles');
title(titlestr);
xlabel('Time(Days)');
ylabel('Tilt Angle');
axis tight
set(gca,'XtickLabel',[]);
set(gca,'XTick',[]);
xlabel('Days 1-30');
if powertilt==1
    lgd = legend('Full Tilt Back','Partial Tilt Back','No Tilt
Back');
else
lgd = legend('Full Forward','Partial Forward','Full
Side','Partial Side','No Lean');
end
title(lgd,'Trunk Movements');

%saveas(figure,fullfile('C:\Users\vosdr001\Documents\1aR21DataAna
lysis\Figures\',['figure7.jpeg']));
%
% %%SAVE to FIGURES FOLDER (Plots 1 through 6 have been done for
all participants)
% for i=1:1:6
%
saveas(figure(i),fullfile('C:\Users\vosdr001\Documents\1aR21DataAnalysi
s\Figures\',['figure' num2str(i) '.jpeg']));
% end
```

Appendix E

*Participant comments; Individualized impact of change in movement with map use based on results shown in Table 7. (For example, ID #2, 15.1 hours per day * .084 * 60 seconds=minutes/day)*

ID	Participant Comments	Observations/Impact
2	"Doesn't take much movement at all to relieve pressure!"	7**6 min/day increase in trunk activity.**
3	"I could see that I was relieving pressure when I leaned and looked at the map. I was more aware of pressure when using the map. I saw a lot of red along one side and couldn't make it better with repositioning. As a result, I made an appointment with seating clinic."	**29 min/day increase in trunk activity, 56 min/day increased time spent in weight shifts.**
4	"Having the mat helped me be more aware of the need to move. I tried to do lifts more often. I used my cell phone's timer to hold them for full minute. But my arms got tired."	**34 min/day increase in trunk activity.**
5	"I don't really do anything to relieve pressure during the day. May use map more as I get older because I know skin changes over time. So far, I've been lucky."	**18.5 min/day increase in trunk activity and 3 min/day more time spent in partial weight shift.**
6	"I'm more conscious of pressure when using the mapping system. I use tilt more when using the mate because I'm way more conscious of pressure."	**21.5 min/day more time spent in partial weight shifts.**
7		**60 min/day more time spent in partial weight shifts.**
8	"Could see differences on map if I changed something. I thought about moving more when I could see the map. I was able to investigate a problem with my cushion and make an appointment to have it checked. This proves how useful it is to have."	**2 hours, 41 min/day increased activity; 3 hours, 7 min/day more time spent in full weight shifts.**

9	"Found the map helpful. When I saw red, I got wigglier in my chair and pressure got better."	**54 min/day more time spent in full weight shifts.**
10	"You can see the pressure, so you're moving more. It reminded me to move."	If there was more movement as indicated by the participant, it may have occurred in small ranges, within baseline position, which increased with map use.
12		**18 min/day increase in trunk activity, 9 min/day more time spent in partial weight shifts.**
14		**55 min/day increase in trunk activity, 60 min/day more time spent in partial weight shifts, 51 min/day more time spent in full weight shifts.**
16		**8 min/day increase in trunk activity; 4 min/day more time in partial weight shifts.**
18		**.53 min/day increase in trunk activity.** *used hours/day from daily log
20		**19 min/day increase in trunk activity; 11 min/day more time in full weight shifts.**
24		**34 min/day increase in trunk activity; 6 min/day more time in partial weight shifts, 8 min/day more time in full weight shifts.**
25	"I found the ability to see my pressure very helpful. I learned I could lean back just slightly and get pressure off my tailbone and that when I lean forward, I completely offload my IT's"	**25 min/day increase in trunk activity; 2 min/day more time in full weight shifts.**